APPAREL ADVANCED MANUFACTURING TECHNOLOGY
DEMONSTRATION

SHORT TERM TASK
AMENDED FINAL TECHNICAL REPORT
PHASES I, II & III

In-Process Quality Control In Apparel Production: Sewing Defects

to

DEFENSE LOGISTICS AGENCY

Short Term Task Under CLIN 0007 of
Contract: DLA 9000-87-D-0018

by

Georgia Institute of Technology
School of Textile & Fiber Engineering

October 1991

October 1991 Final 15 Mar 1989 - 15 Mar 1991

In Process Quality Control in Apparel Production:
Sewing Defects (Unclassified)

Contract
DLA900-87-D-0018/0006

Program Element # 78011S

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Final Report on Phases I, II, and III

Unclassified/Unlimited

This research and development task has the goal of providing an automatic, in-process quality control system for the detection of sewing defects as they occur. Phase I of research efforts is titled "Defects Assessment" and has as its objective the identification of common types of sewing defects. Phase II, titled "Defect Cause and Detection", has the objective of identifying defect cause and potential real-time means of detection of faults. Phase III, titled "Technology Demonstration", has as its objective the laboratory implementation of the detection means for defects identified in Phases I and II. This report covers the work done under Phases I, II, and III.

Apparel Quality Control
Sewing Defect Detection

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Report Contents

In-Process Quality Control In Apparel Production: Sewing Defects

1.0 Project Overview

1.1 Introduction

This amended final report correctly identifies the phases of work done under the contract, and adds information omitted earlier which describes in detail the research efforts. While monthly reports did cover the research details, the previous final report did not adequately describe research findings.

This research and development task has the goal of providing an automatic, in-process quality control system for the detection of sewing defects as they occur. Phase I. of research efforts is titled "Defects Assessment" and has as its objective the identification of common types of sewing defects. Phase II. ,titled "Defect Cause and Detection", has the objective of identifying defect cause and potential real-time means of detection of faults. Phase III., titled 'Technology Demonstration", has as its objective the laboratory implementation of the detection means for defects identified in Phases I and II. This report covers the work done under Phases I, II, and III. A proposal is currently under consideration to implement the results of this work in an industrial environment. Implementation is to occur at sites currently contracting to the government or able to do so. Those sites to be included in the proposed work include commercial and government contractor sites, such as Levi Strauss, Tennessee Apparel and the Factory at DPSC in Philadelphia.

Rapid detection of a sewing defect is important to optimization of the relationship between quality and productivity. Defects found after sewing adversely affect costs. There is distinct advantage to identifying a defect before other operations hinder seam removal and resewing. Also, the automated assembly operations, which are being developed and used in part now and that seen for the future, require on-line quality control if the automation is to succeed. This observation is based upon the current system in which the operator serves as the first line of quality control implementation. Automated sewing stations have no operator to serve in the first line quality control position, leaving quality checks to later stages, after value adding operations are performed on substandard goods. Even multitask workstations need quality control automation, because the operator is handling multiple tasks and is unable to view them all at once. The stress on statistical process control is dependent on automated quality determination in the automated sewing environment.

The research began on March 15, 1989 and has completed its Phase III activities. Additional work was performed in a no cost extension involving graduate thesis research and student special problems. This report follows a series of monthly reports to the DLA which have

detailed regular activities. At the end of seven months a report was prepared as part of the annual reporting of other research groups and a presentation was prepared for the Philadelphia conference. Also, a formal report was prepared in July of 1990, and on two occasions at Cameron Station and once at Clemson University, presentations were made on research accomplishments.

A no cost time extension to the research period has allowed for completion of student projects. Specifically, since funding elapsed, an acoustic approach to identifying needle wear / damage has been found, work on top thread breaks has proceeded with positive results, and an analysis of reliability of acoustic information on thread length consumption has been completed. The latter is important if thread length is to be measured to determine number of ply of fabric. The technical manager of sewing for Levi's stated recently that his first priority was detection of a broken top thread. The research has shown that at least two techniques reliably identify this condition. Additional work is underway to see if infra-red detectors can be used as well, looking at the top thread as it passes over the bobbin case in a lockstitch machine.

1.2 Project Personnel

Dr. L. Howard Olson is the project's principal investigator. Dr. Mathew E. Sikorski is responsible for data collection systems, and Dr. J. Lewis Dorrity is responsible for transducer electronics and data analysis. Dr. Sikorski is on leave of absence at this time awaiting funding of the third phase of this project. The research team management has been to allow shared efforts in all areas and communicate at least weekly on progress and objectives. It has been normal practice for the group to meet daily to discuss results, current needs, and to plan for short and long term objectives.

One M.S. level thesis has resulted from this project. Some eight senior level independent projects have been completed as well. There is a direct benefit to the student and eventually the industry gained through these student efforts.

2.0 Research Review

2.1 Phase I Review

Phase I efforts took two distinct directions of effort. One was to identify sewing defects and in particular to identify those defects which were caused at the sewing machine. The lists of sewing defects discovered by literature search included many defects resulting from fabric or thread defects, but also included defects that were generated at the sewing machine. The second direction of effort was to identify defect detection technologies which might be applied to the defects that were identified. This effort included not only transducer technology, but also data collection and handling

methods. Kinetic Systems provided a CAMAC crate computer system. A Nicolet 310 digital recording oscilloscope, IBM PC (clone) type processing, and data handling software, such as DaDisp and Igor for the Macintosh PC from Apple, were acquired.

Defects found in the literature had many names and were condensed to a reasonable number in needle, machine, operator and thread categories. Examples of these follow.

Needle:

1. Needle picking, fabric damage (burr on needle), needle cuts, blunt needle, needle finish, needle point
2. Needle diameter, incorrect needle size, needle selection

Machine:

1. Skipped stitch (chain stitch), broken stitch, bobbin thread runout
2. unbalanced stitch, stitch length variation

Operator:

1. Raw edge, ply misalignment, sewing off of garment

Thread:

1. Thread damage, broken stitches, improper spool winding

The literature survey uncovered a glossary of sewing defect terms, but most of the terms did not apply directly to the sewing machine, for example, defects in pressing garments. Dr. Sikorski performed a manual search through Textile Technology Digest for the three years from 1987 through 1989, finding information in the general areas of sewing defects, stitching techniques, sewability tests, sewing dynamics, measurement techniques, types of sewing machines, improvements in sewing machines, computerization in the sewing industry, needle technology, and sewing threads. He also did a survey of transducers.

The article content and Textile Technology Digest abstract number are given in the following for reference.

Sewing Defects:	Reference TTD #/year
Sewing damage and prevention	5422/87;2038/88
Zero quality control: Poka-Yoke system	7871/88
Effect of mech. props. on seam slippage	8609/88;1290;88
Fabric defects, seam puckering	2835/89
Relation of plaids to stitching	4525/88;4526/88
Products to improve sewability	8610/88
Sewing lubricant	4553/88
Needle lubrication	462/89
Factorial study of seam resistance	1291/88

The consideration of transducers included resistive and piezoelectric types of devices. Piezo devices were recommended by instrument manufacturers from point of view of their experience and

success with this type of research effort. The companies with whom contact was made are included in the following list.

Transducer manufacturers:	Telephone contact #
Kistler Instrument Co.	(716) 691-5100
Schaevitz Instrument Co.	(609) 662-8088
Entran Devices	(800) 635-0650
Sensor Developments	(313) 391-3000
BLH Electronics	(617) 821-2000
Tensitron Inc.	(508) 456-3511
PCB Piezotronics	(716) 684-0001
STOW Labs	(508) 562-9347
Physical Acoustics	(404) 924-6821
Endevco Corp.	(714) 493-8181

Final selection was made of a series of Physical Acoustics piezoelectric transducers and of a piezo based thread motion detector from Eltex of Sweden, located in Greer, SC.

Interestingly, sewing plant managers with whom discussion of sewing defects was held generally looked to current problems as those which are most pressing or in need of a solution. A day spent reviewing returned goods at one plant showed that of the sewing defects, a raw edge or ply fault was the most frequently encountered sewing defect. Defects such as oil spots, missewn labels and the like were not counted.

The summary results of this phase were that ply faults, i.e. two ply vs. three ply under the needle, thread consumption faults, i.e. wrong stitch density and incorrect needle tension, and needle faults, i.e. blunt or fractured needle tips, were indicative of a majority of direct sewing machine related defects.

2.2 Phase II Review

Phase II. research has had the goal of identifying technologies for sensing sewing defects as they occur. This fits into the long term goal of detecting the more common defects and doing so in a cost effective manner. Acceptance of a detection system in the final system analysis relies heavily upon cost of the system. This means that some optimization must occur between the three interacting considerations within the research: sewing defects, sensing method(s), and system cost. That is not to say that Phase II neglected a technology because of cost either.

Sewing machine manufacturers have been one resource of information on commercially available add-on detectors. Sensor manufacturers are the source of specifications and some history of applications. Acoustic emission (AE) or more appropriately, acoustic energy analysis has been the first line of approach in this research. There is a strong history of success with acoustic energy analysis in many industries. The term acoustic emission has been

applied in airframe and similar industries to the analysis of acoustic energy emitted at a microscopic level by metal grain boundary shear and cracks. This work looks at acoustic energy due to sewing machine vibrations through an approach similar to signature analysis. Whereas sound levels in the early development of acoustic emission work were very low, this work dealt with vibrations of major machine components, primarily the sewing needle, and therefore had the benefit of larger amplitude signals. The work was hindered by the fact, discovered in Phase III work, that stitch to stitch variability generated a spectrum of signals that were not so clear as those found in the early emissions work. Techniques had to be developed in Phase III for dealing with data which were obscured by odd events occurring intermixed with regular events.

Because of the more gross nature of the signals with which this research dealt, this analysis is more appropriately referred to as acoustic energy analysis. The key element of the analysis is the detector of the energy. This is a transducer of the type used in acoustic emission work. A variety of transducers are available. The transducers currently in use in this research are grouped as follows: (1) Physical Acoustics piezoelectric units, model S9223(20 -100kHz), model R-15/C (50-200kHz), and WD (100-1200kHz); (2) Realistic electret microphone, model 33-1052; (3) Eltex single end yarn motion detector; and (4) Spectral Dynamics M99 accelerometer. The accelerometer is attached to the base of the sewing machine by a magnetic coupling and by bolt down. The Physical Acoustics units are coupled with a coupling grease, and the electret microphone is air coupled. The Physical Acoustics transducers were purchased with a 60 dB amplifier (selectable 40 - 60 dB), which also provides transducer bias, and a 0 - 40 dB postamplifier.

There are several considerations which must be added to simple acquisition of transducers and data recording instrumentation to avoid false information. In particular consideration is given to data sampling rate and its influence on data validity, i.e. aliasing and the need for filtering.

2.2.1 Data Sampling Rates

The analysis of data from engineering experiments has been greatly facilitated by advances in computer and software technologies. One of the main steps in such analysis is to digitize the signals from transducer devices. In doing this, one must be aware of the Nyquist (sampling) theorem. This theorem states that the minimum frequency which can be used for digitization without losing information is twice the highest frequency of interest. This is described in many texts and one which describes well the reasoning behind the theorem is Kuo.[1]

[1]Kuo derives the transformation from the time domain to the frequency domain which shows that a sampler is a harmonic generator. The text illustrates the replication of a signal spectrum at intervals of the sampling frequency, w_s. As w_s approaches the highest signal frequency, w_c, the sidebands begin to overlap the original signal spectrum thereby giving erroneous or false results. The closer the frequency of interest is to w_c, the more erroneous the results. Thus the theoretical limit is stated as above. Practical filter design makes it prudent to sample at a somewhat higher rate, perhaps $w_s > 3\ w_c$. A filter with a cutoff frequency "close to" the highest frequency of interest should be employed to prevent the generation of false output information.

2.2.2 Aliasing

Another problem which can occur in digital sampling is called aliasing. This is a problem which causes a frequency to appear to be much lower in frequency. This may be visually observed when using a strobe light with a rotating object. When the flash (sampling) frequency is lower than the frequency of rotation, the object appears to be rotating at a different frequency than it actually is. The original waveform occurs at one sampling rate while the aliased signal occurs at a rate one fifteenth as fast. This causes the observed signal to be less than the actual signal.

At first, the two problems discussed above may seem to be the same phenomenon. However, in the first case there is a non-existent waveform appearing superimposed on a real waveform and in the second case an existing waveform appears at a different frequency than it actually is.

2.2.3 Filtering

From the above discussion, a conclusion should be that frequencies above those of interest or approaching the sampling limitation must be attenuated. This may be done electronically by using operational amplifiers and appropriate feedback circuits. In this method the filtered waveform is sampled and analyzed. The alternative is digital filtering.

Digital filtering may also be employed by calling appropriate software algorithms in the computer. If real time processing is needed and the sampling rate requirement is too high, then the digital algorithm may not be fast enough. One must also be aware that filters are not ideal. Frequencies near cutoff, while reduced by a certain db of loss, may still be present in the sampled signal. This relates to filter circuit Q, or quality factor. A Kronhite analog filter with bandpass, high pass, and lowpass selections over

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[1] Kuo, Benjamin C., <u>Analysis and Synthesis of Sampled-Data Control Systems</u>, Prentice-Hall, 1964

the frequency range 0 - 1,000 kHz has been chosen for this research.

2.3 Phase III Results

This phase of research began the in earnest identification of means of detecting sewing defects and demonstrating on the laboratory equipment that it could indeed be done. While originally the lab facility at Southern College of Technology was proposed for doing demonstrations of the lab setup, a laboratory was set aside at Georgia Tech for the apparel research so that research would not be interrupted by transporting equipment off site. The following describes the developments in this phase of research.

Defects such as thread line presence and number of fabric ply have been investigated by means of acoustic analysis. The steps involved include taking numerous data points and applying a Fast Fourier Transform to the data to acquire a spectrum of amplitude versus frequency. Because of phase differences in energy emitted at each cycle of the sewing machine, time domain data cannot be averaged. On the other hand, data transformed to the frequency domain can indeed be averaged over multiple cycles, smoothed, and thereby analyzed for differences in spectra when defects are introduced.

The purpose of the initial efforts at data acquisition were to test the acquisition system and the data packages. The JUKI sewing machine provides in the electronic controller a top of cycle or bottom of cycle pulse for triggering data acquisition. Included below successively are figures of a signal made while the machine is running over a single layer of fabric and a noise signal amplified to be of similar amplitude to the running signal.

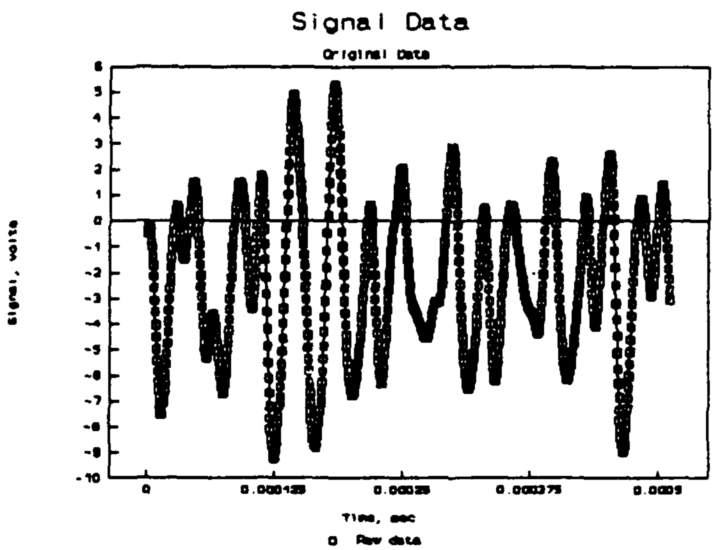

Figure 1 Signal from Operating Machine

The noise image similar to the above in Figure 1 is shown in Figure 2 following.

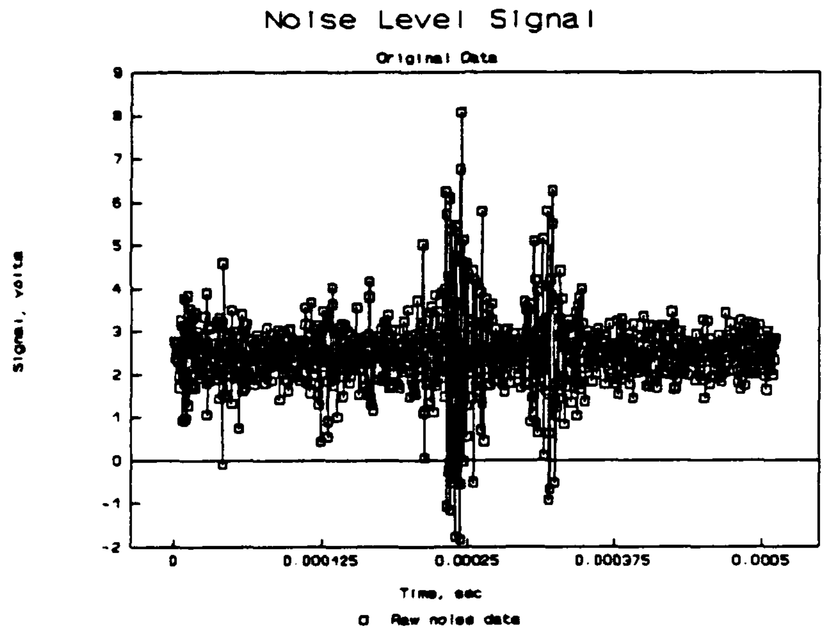

Figure 2 Amplified Noise Data

Both images have the same number of data points and the same sampling frequency (1024 points, 500ns interval). Expanding the noise signal leads to finding what appears to be periodic information. The true test of noise versus interesting content comes with analysis by means of the Fast Fourier Transform (FFT) and the spectrum (normalized, real portion).

To illustrate this the spectra of both Figures 1 and 2 are represented respectively by Figures 3 and 4. These follow on the next page.

The spectra clearly show which has periodic signal content and which has none. The noise signal rests on or at the zero axis, indicating no amplitude was found at any particular frequency. The operating signal has something happening at 15 to 30 kHz and perhaps harmonics or other signals at 45 to 60 kHz.

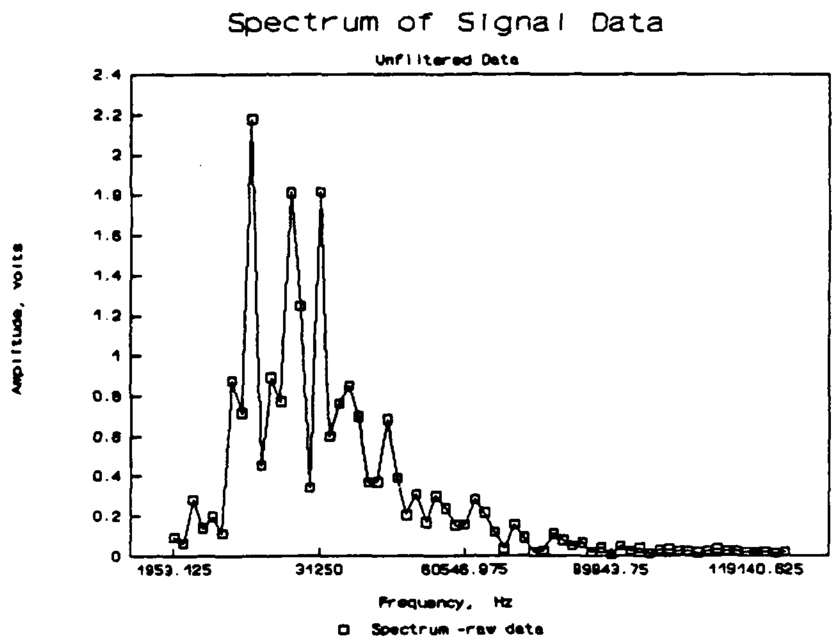

Figure 3 Spectrum of Data with Signal

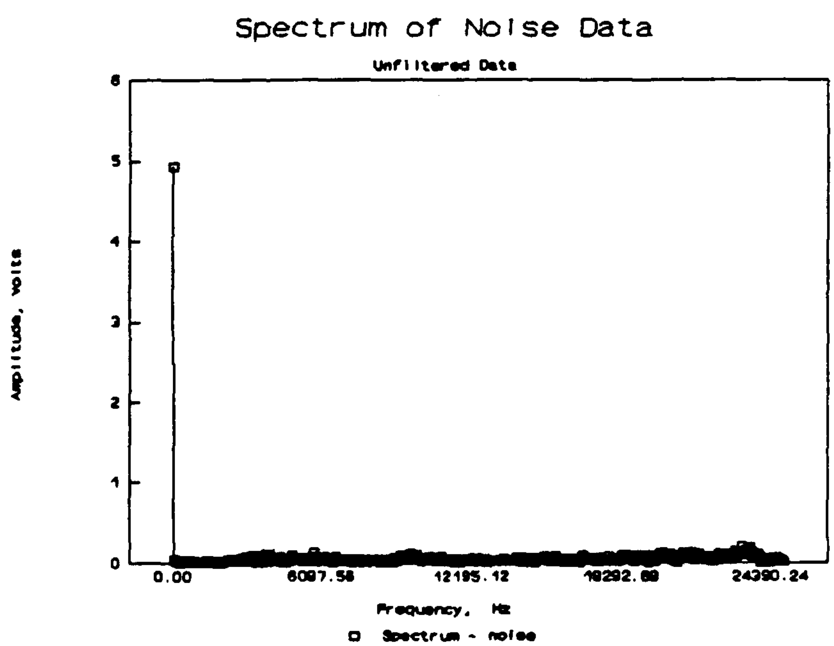

Figure 4 Spectrum of Noise Data

The FFT is done on periodic functions. The fixed interval data sample has discontinuity at the ends. There is an effect on the spectrum caused by the energy artificially generated by the data edges. Routines which taper the end points of a non-periodic signal so that they match is referred to as a windowing function. Several known by name are the Hamming, Hanning and Kaiser functions. To see the effect of the window on the signal spectrum, the following two figures give the data equivalent to that in Figure 1 and Figure 3 with the Hanning window applied.

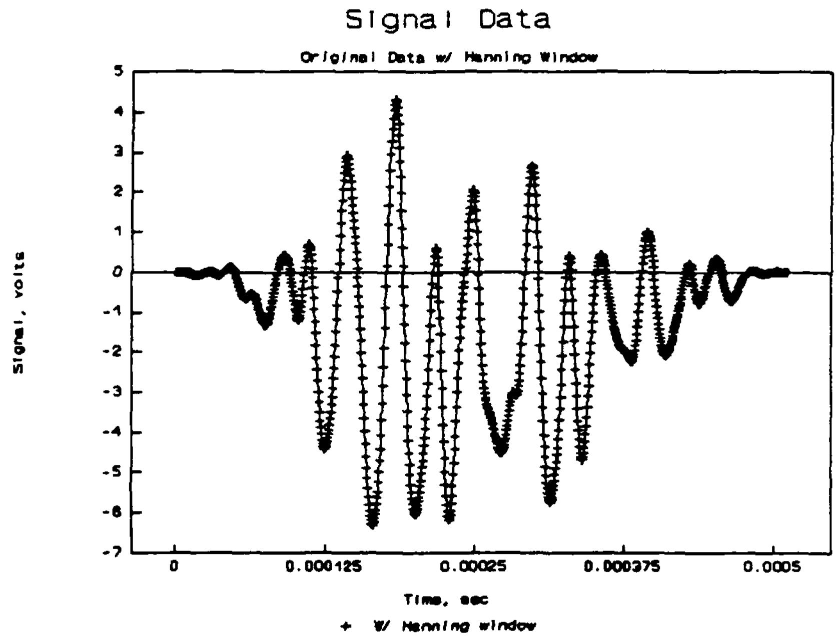

Figure 5 Signal Data with Hanning Window

Figure 5 above indicates only the shape of the windowing function when compared to Figure 1. The purpose of doing this is to determine if windowing alters the spectrum. For that the next figure illustrates the spectrum after windowing.

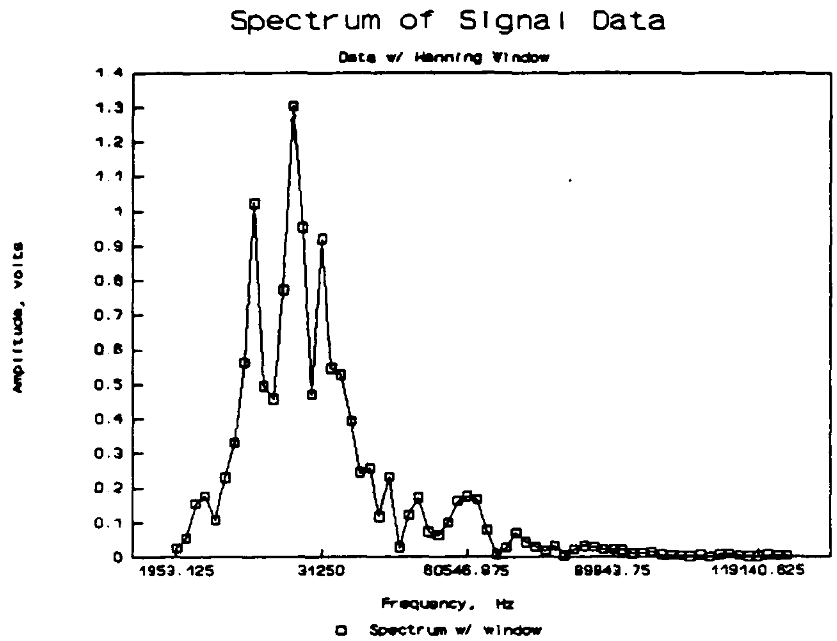

Figure 6 Spectrum of Hanning Windowed Signal

Superimposing these two shows that the frequencies remain intact. Amplitude is changed somewhat, but that significance is not certain at this time.

The above does indicate that techniques such as averaging of data over five or ten cycles, or averaging the spectra may be useful in detecting rapidly where changes occur due to process changes. There is a significant amount of process and random noise outside the acoustic energy related to process change for which detection is needed. This is part of the early work necessary to set up efficient investigation of sewing defects.

An ambitious program was set forth to gather data in an orderly fashion to begin the search for an acoustic signature which indicated the number of plies of fabric being penetrated by the needle. There is an early indication that some success may be had in this approach. Neither the raw data nor a spectrum alone is sufficient to identify the number of plies of fabric under the needle. But taking the difference between two spectra with one and two plies, for example, shows promise at frequencies of about 5 and 15 kHz, and at 8.80 kHz

for a machine speed of 2000 RPM.

Figure 7. following is of the difference between two spectra taken at one ply and at two ply. Each waveform data specimen of 4000 data points had covered about two machine cycles. Five data specimens were taken at each ply level, one and two. Spectra were calculated for each data specimen; and the average of the five spectra in each set was used to form the difference spectrum shown below.

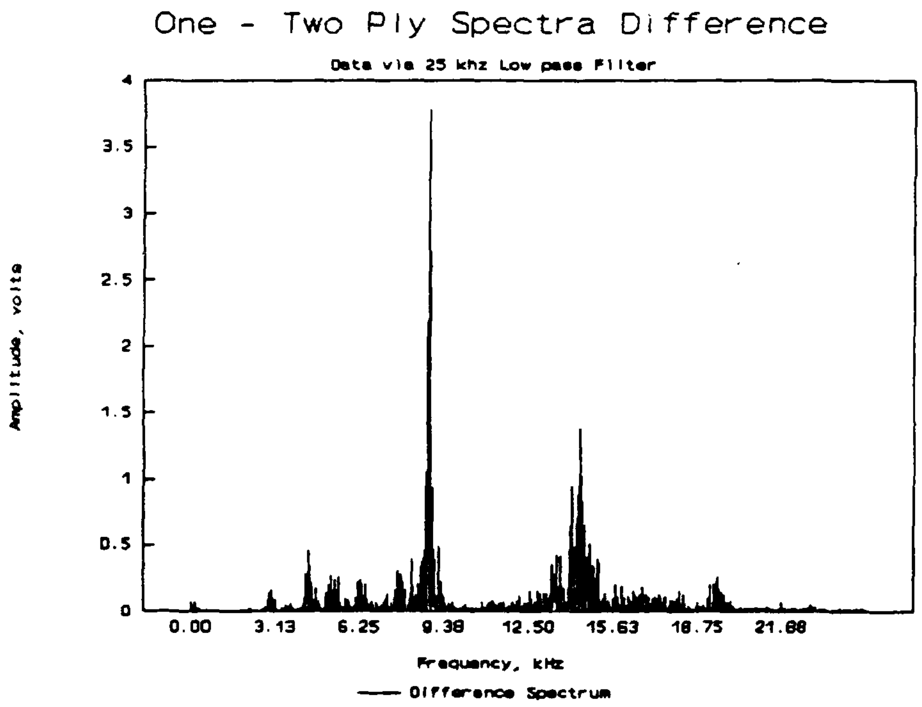

Figure 7 Preliminary Data on Ply Spectra Difference

The significant peak at 8.80 kHz suggests that a single frequency narrowband sample at this frequency would be sufficient to discern between one and two ply. This result led to further research on fabric ply detection, particularly at higher speeds.

2.3.1 Timing and Sample Size

The data collected was done at a sewing machine speed of 3000 RPM and at a 10 usec sampling rate on the Nicolet 310. Sewing at 3000 RPM is equivalent to 50 cycles per second or, taking the reciprocal, 20,000 usec. per cycle. The Nicolet collects 4000 points per data sample, and at 10 usec. per point will collect 40,000 usec. of data. This then corresponds to exactly two cycles of the sewing machine. With the time continuity of each sample assured, the triggering of the start point of each sample remains to have equivalent samples for analysis work.

Triggering fortunately is provided on the JUKI sewing machine by a Hall effect type device mounted on the machine flywheel (handwheel). The triggering is repeatable on successive cycles at constant operating speed. The trigger point is at top dead center. This means that duplicate sets of data were available and in integral number of cycles per sample set. The concatenation of raw data prior to FFT analysis is one use of these controlled data sets. Secondly, the FFT algorithm relies upon having a power of two as the length of the data set. If a discontinuity is introduced into the data by adding artificial data to the end of a data set, e.g. 4000 data points plus 96 zeroes, then a piece of artificial information is added to the FFT. Data presentation for analysis should have 4096 valid data points.

2.3.2 Data Presentation for Analysis

With integral machine cycle data increments, it is sufficiently easy to duplicate the first 96 data points as the last 96 points in a set of 4096 data points for the analysis software. The FORTRAN software which was prepared for reading the binary data off of Nicolet disks also gives essential information headers about the data, groups successive sets of data in lots of five sets, fills the data to 4096 data points, and reformats the internal representation of the data to ASCII representation with six decimal places. With the work that has been done to write Igor macros for the actual analysis, the system is reasonably automated. That is to say that in about thirty minutes on the lab computer (an IBM PC), an Igor ready disk can be prepared from a Nicolet disk. Incidentally there are multiple Igor disks involved in completely resolving all the data on a Nicolet disk. Then in an additional thirty minutes, Igor can provide FFT magnitude spectrums of the data on a Macintosh. Five spectrums are generated and averaged in a typical analysis group.

Images created on the Mac have been successfully transported in TIF format from the Mac to an IBM PC and vice versa. The images in this report happen to be regenerated from Mac data using Lotus 1-2-3 rather than being TIF files.

2.3.3 Data Evaluated and Results

The data taken was for one fabric ply under the sewing head, two

ply, and three ply. The acoustic sensor was coupled to the bed plate near the needle. Twenty five samples were taken at each fabric ply level. This is seen as providing certainty through averaging of random noise and false signals, the goal of taking large data sets. Each ply level was thus represented by fifty cycles of the sewing machine.

At 6500 khz approximately there were pronounced peaks in each of the data sets (1, 2, 3 ply) which were quite similar in magnitude. The data at these peaks and elsewhere along the curves despite the averaging of 50 sets was "bumpy", having oscillations in magnitude while also having very clear trends. Curve smoothing using a Pascal triangle approach resulted in removing many of the bumps.

At 8765 Hz there were peaks which clearly showed some effect was taking place. Figure 8 following illustrates the bumpy data and trend seen in the 8500 - 9000 Hz increment.

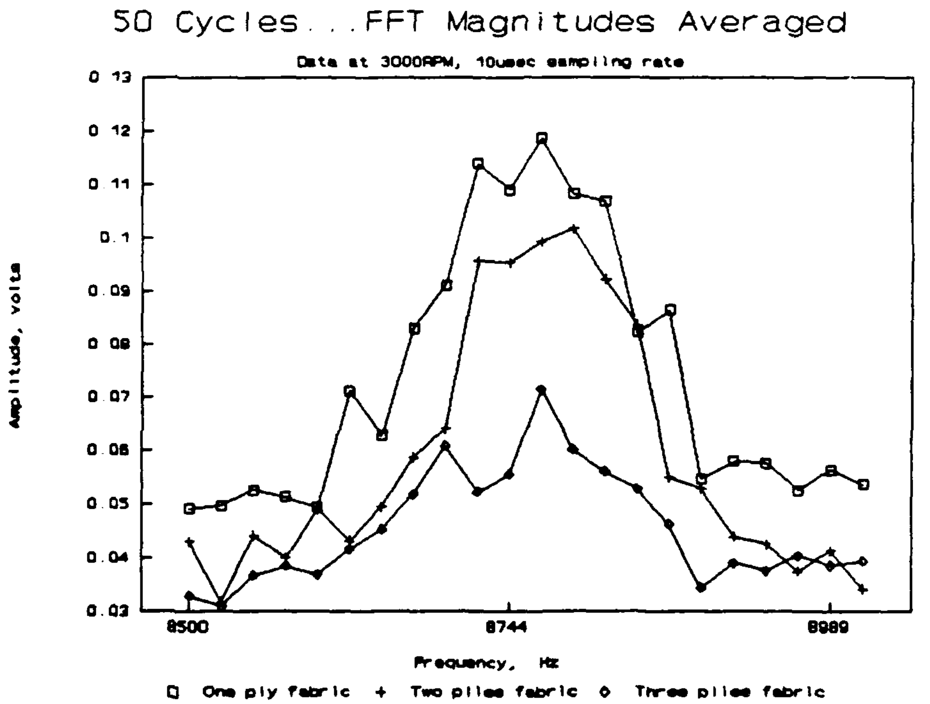

Figure 8 Twenty Five Data Sets Averaged

This data represents the averaging of twenty five spectrums or the magnitude of twenty five FFT's. Despite the benefit of averaging data, there is a roughness to the data. The next step was to smooth the data. An example of smoothing is shown in Figure 9. This represents the data in Figure 8 smoothed by a (1,4,6,4,1) weighting of surrounding data, the weighting being taken from Pascal's triangle. This was done in a spreadsheet from numbers given by Igor in a 0 - 50,000 Hz spectrum.

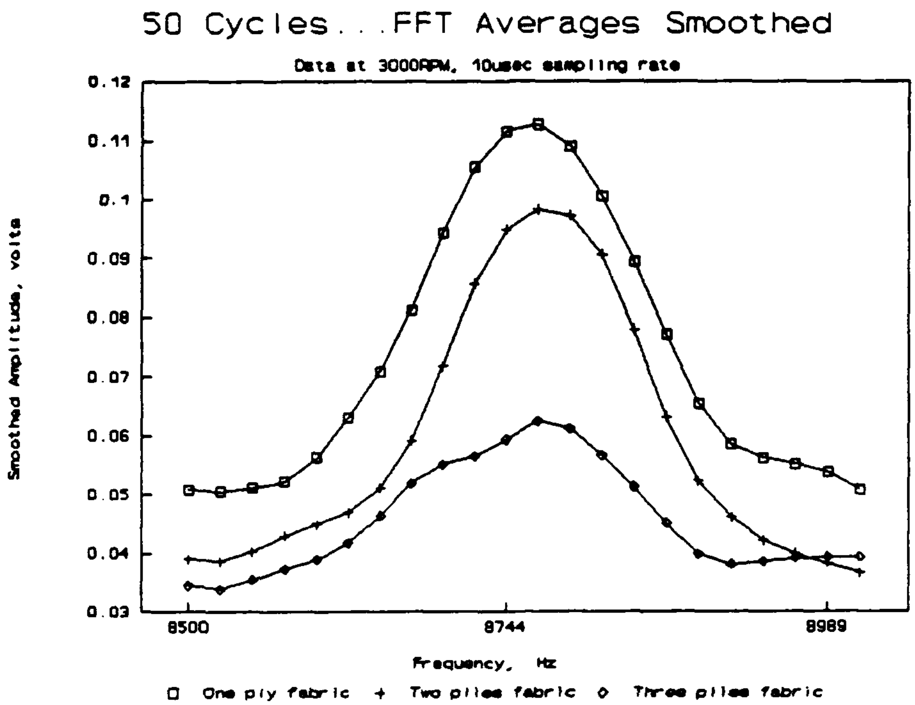

Figure 9 Smoothing Function Applied to Data

This appears much more acceptable. If there is any problem with the smoothed data, it is that there appears to be a non-linear relation between number of ply and the acoustic response at about 8765 Hz. Incidentally, the figure of 8765 Hz was found by manually searching the Igor spectrum for the peak value and observing that it was consistent from one ply level's data set to the next.

Recalling the consistency in amplitude found at just over 6500 Hz, normalization was tried by dividing all the data by the data value average in the 6500 - 6550 Hz range. The result of doing this gave the best appearance of plotted data yet obtained. The effects of normalization and smoothing are shown in Figure 10 below.

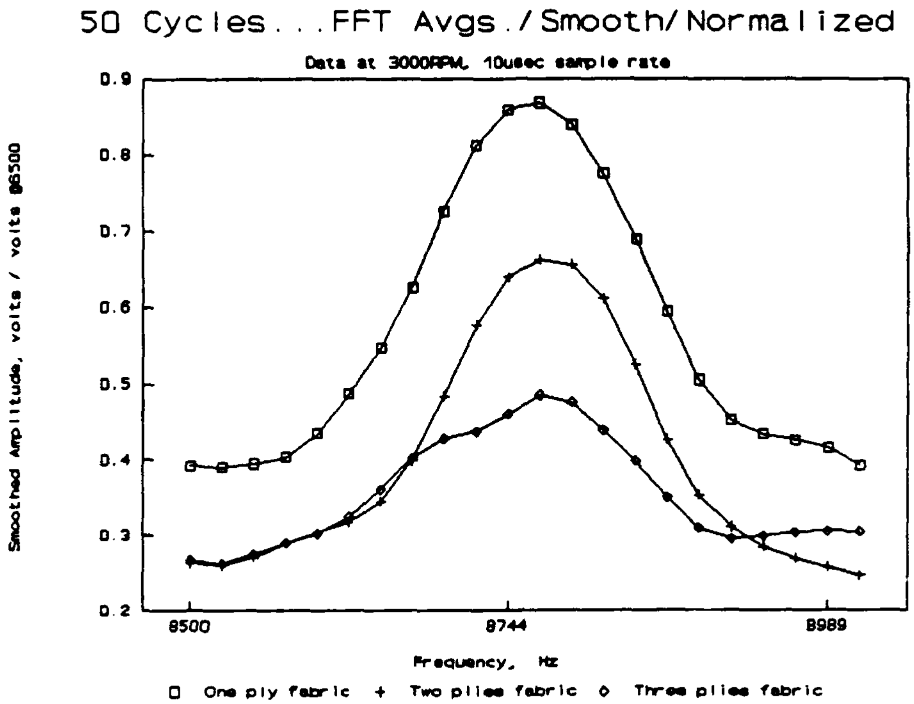

Figure 10 Normalization Applied to Smoothed Data

The data in the 8725 to 8775 Hz range show a nearly linear step size from one to two to three ply. This is as clear and as promising as one could expect of a research result. The next question is what precautions should be taken. Later research showed that significant samples only could provide reliable results. The ideal of a single stitch ply fault detector is an unreasonable expectation on a lockstitch machine.

Investigation of acoustic signals before and after a thread break shows that there is good correlation with a band of frequencies at 6000 to 7000 Hz and at 8700 to 8800 Hz. There was found in the data a recurring peak, as well, at 14.5 kHz.

2.3.4 Thread Break

There are one or two additional observations that can be made at this time. The data shows a broad decrease in the total energy of the spectrum as the change from thread in the needle to no thread in the needle is made. The no thread condition has the lower amplitude generally.

A demonstration was made with the M99-1 accelerometer screwed directly to the machine bed. The output was directed through an accelerometer amplifier to a filter, then an audio amplifier and audio loud speaker. The change in sound made by the machine as the thread was cut was clearly discernible. This demonstration suggests strongly that a method of detecting thread breaks could be based on an integration of fixed period of the accelerometer signal.

Both raw data, which has the appearance of an amplitude modulated wave, and the spectrum yield information about what is occurring in the sewing area. Dr. Sikorski noted that he could hear a sound change when the thread broke. Indeed, the average power in the emissions decreases when the thread breaks. This is indeed significant when considering the simplicity and therefore cost of detection means. Direct analog filtering and voltage comparison is inexpensive to accomplish. On sewing machines with built in microprocessors, more sophisticated analysis may occur.

A series of extended runs was made to investigate the frequency content of acoustic signals before and after simulated thread breaks. All of the data were obtained thus far at a machine speed of 3000 RPM after a very careful tension adjustment for the needle and bobbin threads to produce "normal" stitches.

The experimental procedure consisted in obtaining between 30 and 35 wave recordings with the help of the Nicolet 310 oscilloscope. Curves obtained in this manner represented "normal" sewing conditions. The second set of 30 or more wave recordings was obtained when the machine was run without the thread in the needle simulating the thread break condition. The thread vs. no thread curves were then compared with the help of the Igor and DADiSP software packages.

2.3.4.1 Comparison of Thread/No Thread Curves

There are distinct frequency bands that might be useful for the detection of thread breaks. These are: (1) 6000 to 7500 Hz; (2) 8700 to 8800 Hz and (3) 14000 to 16000 Hz (particularly the lower part of this latter band). Since band (2) is being considered for possible use in the determination of the number of fabric ply, an evaluation is given only for bands (1) and (3).

The DADiSP software, installed in an IBM PC/XT computer, allowed the extraction of sections of experimental curves, thus simulating electronic filtering. In addition, it was possible to determine quantities such as areas under curves, mean values of signals in selected frequency bands, as well as the ratio of these quantities under thread/no thread comparison conditions.

The curves obtained for thread vs. no thread are illustrated in the next figure.

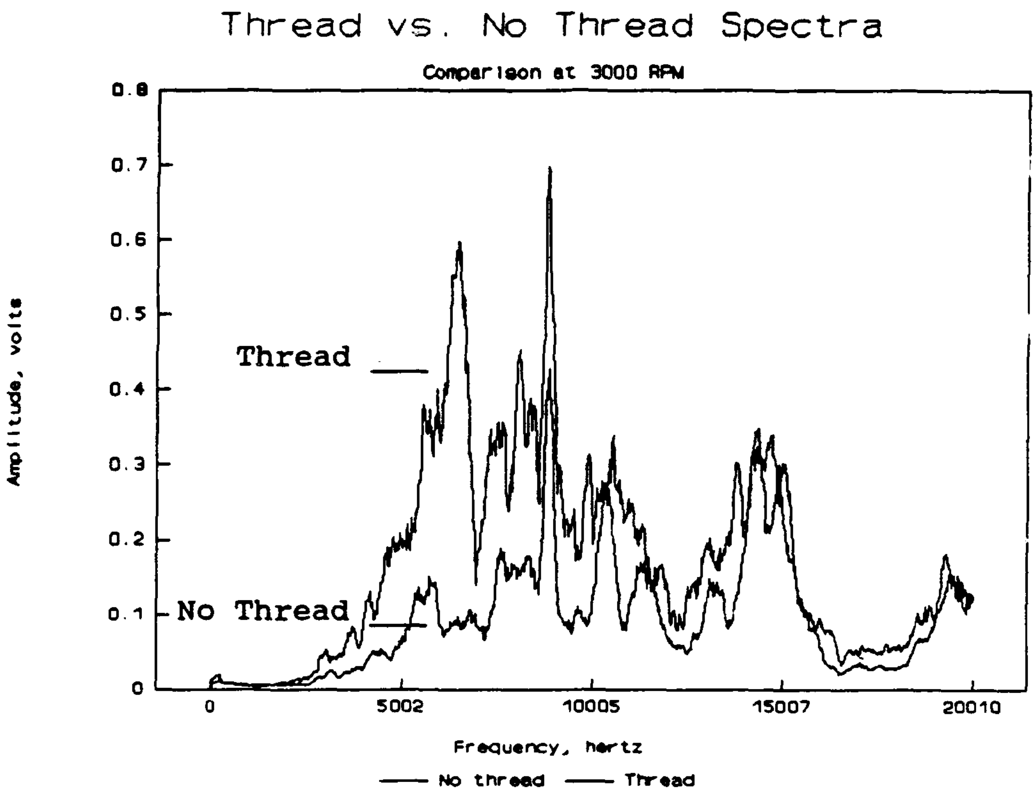

Figure 11 Thread vs. No Thread Comparison

An example will now be given of the comparison of the "thread" (T) vs. "no thread" (NT) curves in frequency bands (1) and (3) defined above.

In band (1) the acoustic energy decreased when the needle thread was cut while the opposite was found to be true for band (3).

The results for band (1) were as follows:
{ T infers thread, NT infers no thread }

Area(T) =253 V-Hz { V-Hz is taken as the units of area under the FFT spectrum curve being analyzed: V, volts amplitude (Y-axis) vs. Hz, frequency (X-axis) }

Area(NT)=156 V-Hz and Area(T)/Area(NT)=1.63 V-Hz and

Mean(T) =0.083 V

Mean(NT)=0.053 V and Mean(T)/Mean(NT)=1.57 V

Similarly, the results for band (3) were:

Area(T) =121 V-Hz

Area(NT)=229 V-Hz and Area(NT)/Area(T)=2.20 V-Hz

Mean(T) =0.072 V

Mean(NT)=0.158 V and Mean(NT)/Mean(T)=1.89 V

The above results show that the observed changes in the experimental curves with needle thread and without are large enough to warrant the use of these effects for the construction of a thread break detector. This would require construction of electronic filters centered around frequencies of 6500 and 15000 Hz for the two bands (1) and (3) considered.

The status of acoustic energy analysis applied to sewing is that thread breaks are positively identified. Integration over the spectra or filtering and summing two or three frequencies can accomplish this. A filter circuit with a Q factor of 100 may be sufficient to detect thread break faults. Op amp (operational amplifier) active filtering can achieve the Q so long as parts tolerance in held at a high level or compensation is used at the time of circuit design. The next step is considering machine speed over the feasible range of apparel plant operations.

The work was extended to encompass the following eight sewing machine speeds: 1680, 2127, 2564, 2985, 3389, 3846, 4255 and 4651. Careful tension adjustments were made for the needle and bobbin threads in order to produce normal stitches. For the evaluation of each experimental condition four waves were imported into DADiSP and then analyzed. The analysis consisted of obtaining frequency spectra of each of the waves and getting an average spectrum for further study.

2.3.4.2 Machine Speed Effects

The illustrations in this section depict general characteristics of sound spectra recorded in the frequency range 0-25kHz for different sewing machine speeds. Figure 12 shows average spectra of sound waves obtained during normal sewing of two ply of utility trouser fabric. The upper curve corresponds to a machine speed of 4255 RPM and the lower one to 2985 RPM. Both of the curves are typical of normal sewing with the needle and bobbin threads being properly pre-tensioned.

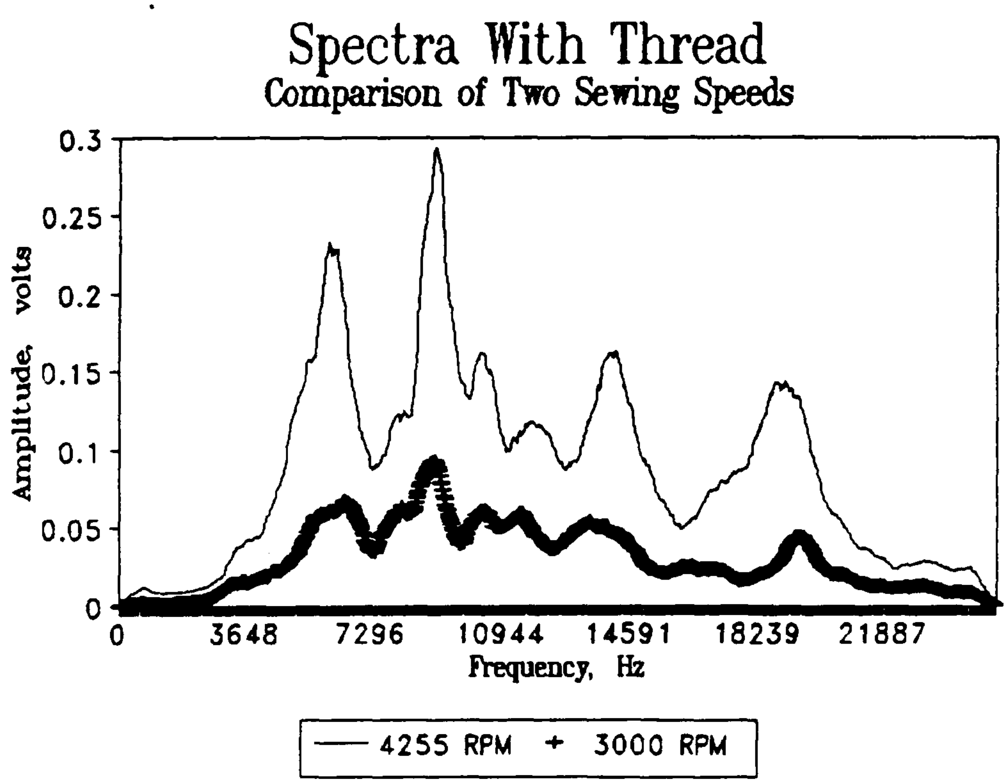

Figure 12 Direct Comparison of Effect of Sewing Speed on Spectra

The purpose of Fig. 12 is to illustrate that both curves are similar in shape; however, the 4255 RPM curve is characterized by a much greater acoustic output.

The next two figures illustrate a different comparison, namely, sewing both with and without the needle thread. Figure 13 depicts average acoustic spectra of acoustic waves under Thread (T) and No Thread (NT) conditions obtained at a machine speed of 1680 RPM.

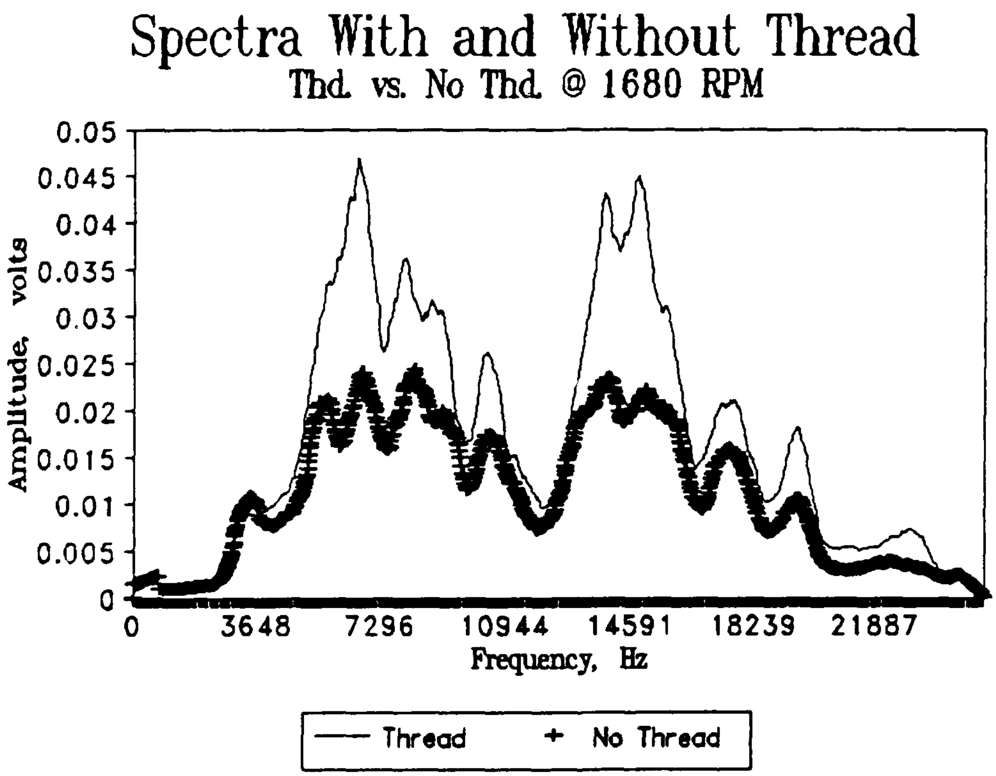

Figure 13 Low Speed Comparison of Thread vs. No Thread

Figure 14 on the next page shows similar data except obtained at a machine speed of 4255 RPM.

Observe the reversal of the relative position of thread and no thread curves between figures 13. and 14.

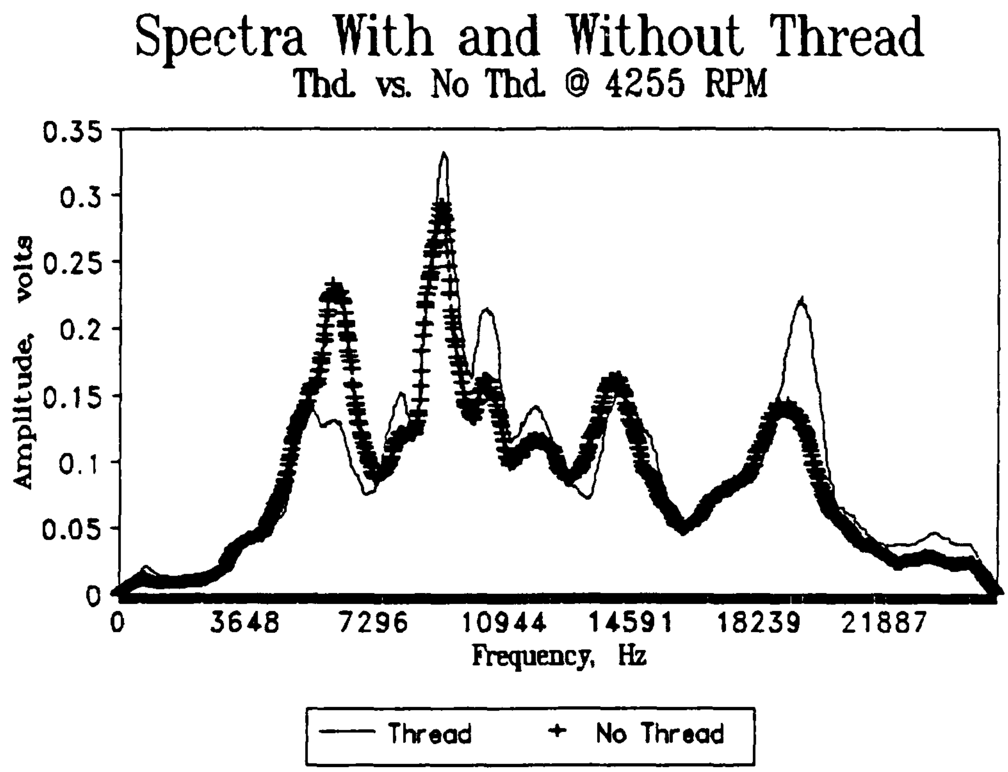

Figure 14 High Speed Comparison of Thread vs. No Thread

The significant difference between the two cases is that the acoustic output for the 1680 RPM (NT) curve is much lower, almost in the entire frequency band, than for the (T) curve. The situation is reversed in the 4255 RPM case. The acoustic output is greater for the (NT) curve. This condition was also found to be true for all remaining six machine speeds investigated (see Figs. 15 and 16).

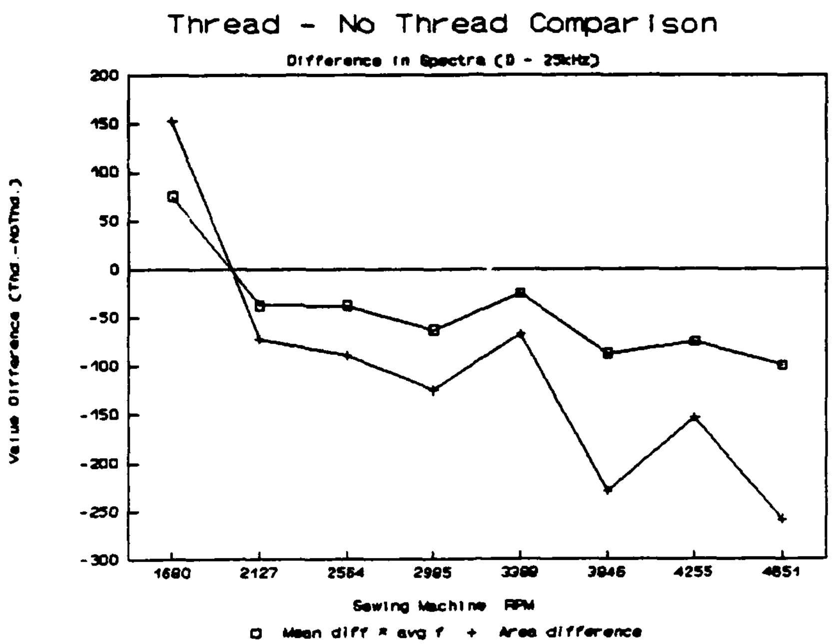

Figure 15 Difference in Thread - No Thread Spectra vs. Speed

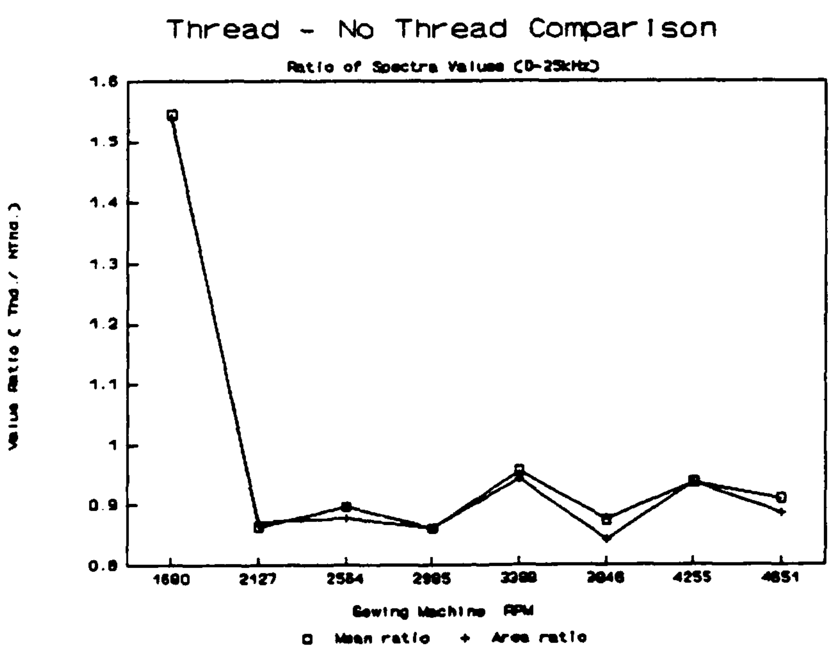

Figure 16 Ratio of Thread - No Thread Spectra vs. Speed

In Fig.15 differences (and in Fig. 16 ratios) between the calculated areas under the No Thread and Thread spectral curves, as well as mean voltage values for these are plotted against the sewing machine speeds. Note that the points for the 1680 RPM curves are located below the zero line in accordance with the results presented in Fig 16, above. These results point to the fact that the acoustic outputs for Thread and No Thread conditions in the spectral range of 1-25kHz are equal somewhere in the vicinity if 2000 RPM.

In the next section detailed results are presented to illustrate the approach that has been developed to build a thread break detector based on sewing machine acoustics.

2.3.4.3 Conclusions

A number of frequency bands were selected for possible use in the detection of thread breaks. An updated listing of these bands, based upon these figures, is as follows: (1) 4.0-7.3 kHz; (2) 13.5-16.5 kHz; (3) 19.0-20.3 kHz and(4) 13.5-20.3 kHz. Band No. (4) includes the acoustic content of bands (2) and (3).

The DADiSP software was used to perform filtering or band selection of the 0-25 kHz spectra into the bands given above. After performing the above extractions, it was possible to calculate the areas under the curves and the mean values of signals in the selected frequency bands. Figure 17 shows the combined results for the above listed four frequency bands of an evaluation of the difference of areas under no thread/thread comparison conditions for the different sewing machine RPM.

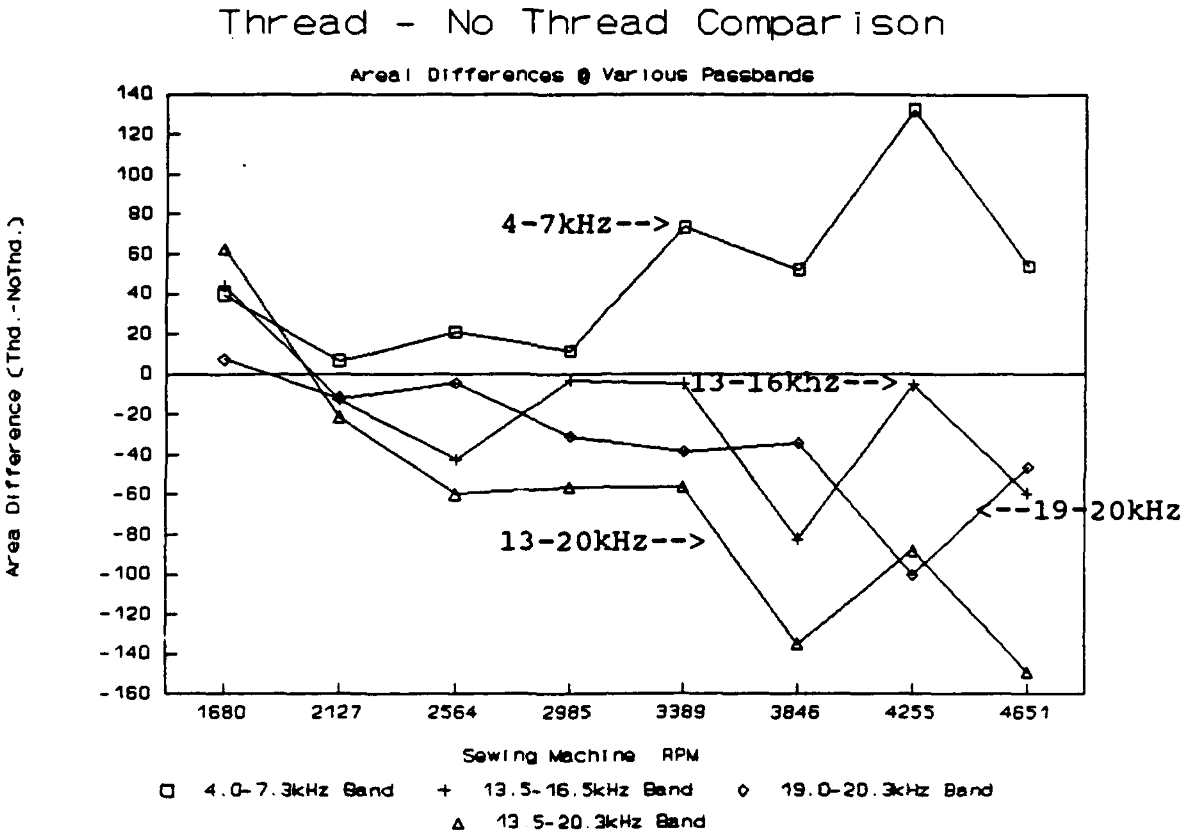

Figure 17 Thread - No Thread Differences in Passband Increments

The contents of band (1) behave quite differently from that of all the other bands. While the acoustic signal of band (1) decreases when there is no needle thread, that of the other three bands increases. Parenthetically, band (4) combines the output of bands (2) and (3) and augments it by an additional range of 16.5-19.0 kHz. Consequently, the area difference for band (4) is greater than the sum of the corresponding quantities for bands (2) and (3).

A thread break detector could be built by monitoring the output from electronic filters for extracting signals from frequency bands (1) and (4). For machine speeds lower than 2000 RPM, a thread break would be characterized by a sudden decrease in acoustic energy (at a constant sewing speed). For sewing speeds greater than 2000 RPM, a thread break would result in a sudden increase in monitored acoustic output.

2.3.5 Thread Tension

Thread tension produces a defect when top to bottom thread tensions become severely imbalanced. This affects lockstitch formation, determining whether the junction of top and bottom threads is adequately hidden from the surface of the fabric ply structure. Too much top tension causes the bobbin thread to be pulled completely to the upper surface of the fabric. This is a visual defect as well as one which reduces seam abrasion resistance. The FFT of a series of stitches changes visibly when the tension is off to the top or bottom. Acoustic measurement offers sufficient promise to merit its use in this application.

Five data sets related to needle and bobbin thread tensions have been analyzed using DADiSP software. The extractions of spectral data were made in similarity with the evaluation of thread break results. However, only two frequency bands were taken, namely, 4.0-7.3 kHz and 7.3-21.5 kHz in addition to the broadband data for 0-25 kHz. A graphical representation of the tension results is given in Fig. 18, below.

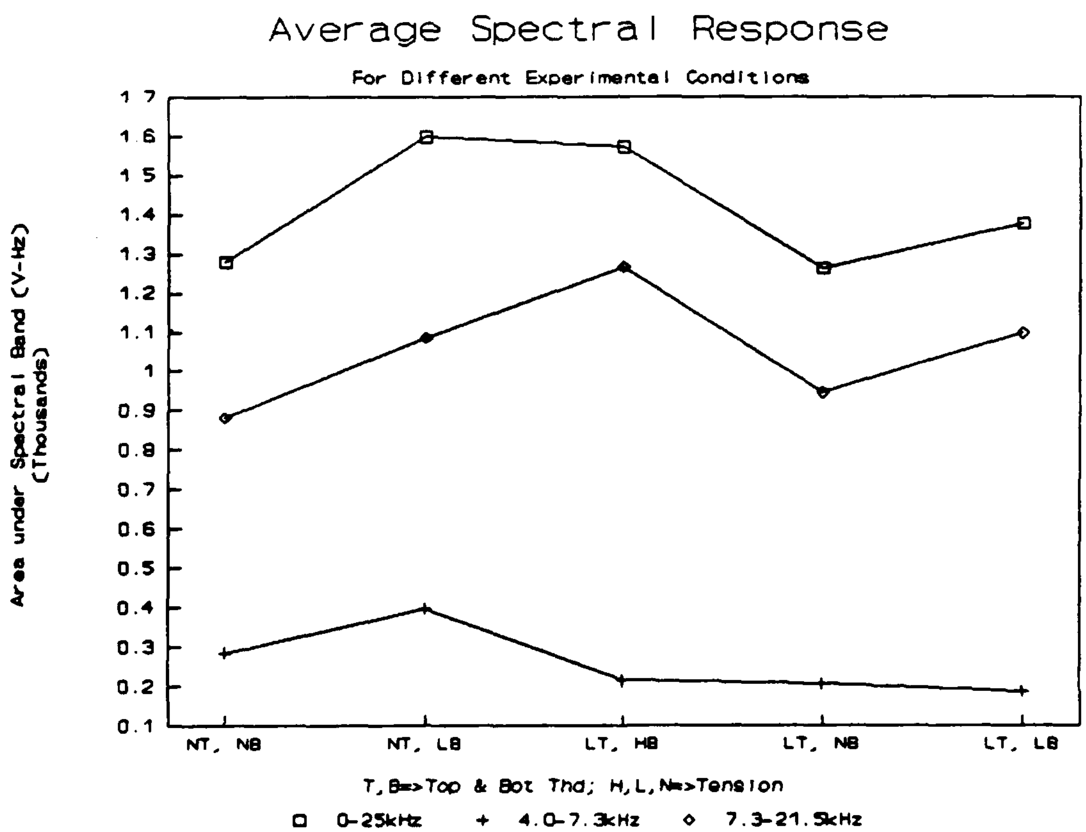

Figure 18 Area Under Spectrum, Various Bands

Figure 18 shows the results obtained on five sets of data rendered for the following experimental conditions:(1) Normal needle thread tension (NT) and normal bobbin thread tension (NB);(2) NT and low bobbin thread tension (LB); (3) Low needle thread tension (LT) and high bobbin thread tension (HB); (4) LT and NB and (5) LT and also LB. The points for the three frequency bands carry different designations. Each point represents an average of four data sets.

The results of Fig. 18 indicate that it should be possible to detect a number of sewing defects by monitoring signals from one or more electronic filters. For example, the difference between conditions NT,LB and LT,NB should be detectable using the low frequency band signal. However, in order to be able to distinguish between the three low needle tension conditions, it may be necessary to also monitor the high or broadband frequency signals.

In summary, both thread break and abnormal tension conditions in the needle and bobbin threads appear to be amenable to the acoustic energy analysis.

To better quantify the experimental results, measurements were taken of the needle thread tensions as a function of the position of the thread tensioning knob and of the bobbin thread tension by noting different positions of the spring tension adjustment screw. First, needle tension results are presented.

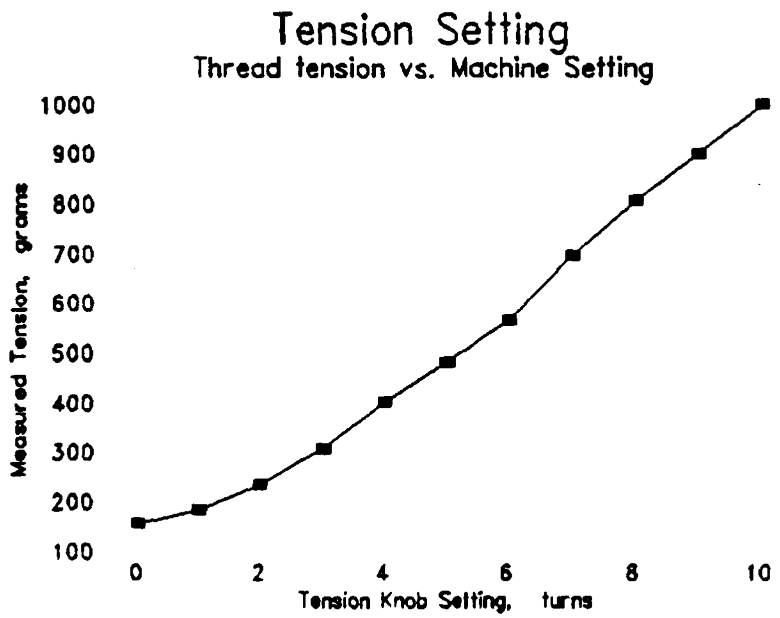

Figure 19 Thread Tension and Machine Setting

Figure 19 shows experimental results on the tension values of the needle thread as a function of position of the tensioning knob. The zero position corresponds to the proximal surface of the knob being flush with the end of the shaft of the tensioning attachment. Each point on the graph is an average of ten measurements made using two Ohaus spring scales graduated in grams. The ranges of these scales were: 0-250 g and 0-2000 g. Only full turns of the knob were considered. Measurements of this type should be very useful in quantifying future experimental work on other types of machine.

The thread tension in the bobbin was evaluated with the help of the spring scale with the range 0-250 g. It takes approximately 1.5 turns of the screw to go from an essentially zero tension to a maximum of 125 g for an extreme clockwise position of the tightening screw. Average values for ten measurements were: for 0.5 turn, T=12 g; for 1.0 turn, T=75 g and for 1.5 turns, T= 125 g with a pronounced stick-slip effect. For optimum sewing conditions the screw setting should be between 0.5 and 1.0 turns.

2.3.5.1 Thread Tension Faults

In discussion above, average spectral responses are displayed in Fig. 18 for different experimental conditions and various frequency bands. The quantities plotted were for the area under different spectral bands. Preliminary data were obtained for the output voltage generated in the 4.0-7.3 kHz band for different experimental conditions. The voltages were measured using a general purpose Beckman 310 multimeter.

The following general results are given for sewing of two ply of fabric at 2100 RPM and 46 dB of signal amplification:

For normal needle and bobbin tensions the approximate output voltage [V(out)] from the transducer was about 0.3 Volts AC;

For conditions of high needle and bobbin tensions V(out)=0.4 Volts AC;

Finally, for low needle and bobbin tensions V(out)=0.2 Volts AC.

More accurate results may be obtained using a meter that reads true RMS voltage values. The significance of this is that an inexpensive device can be designed to detect thread tension variation from a normal value range.

2.3.5.2 Thread Balance Considerations

For a denim fabric and a reasonable needle thread tension, the distance from bottom to top from the interlock point was closer to 25%-75% than 50%-50%. The needle thread looped the bobbin thread near the bottom of the fabric ply. This condition was attained when the top thread tension was kept sufficiently high to prevent loop formation on the bottom of the fabric but not high enough to cause

the puckering of the fabric after sewing.

In all cases, including that of perfect balance for two plies of fabric, i.e., when the needle thread and bobbin thread lengths are equal in a two ply seam, the needle thread was shorter than the bobbin thread for one ply and longer for three plies. In all studies the bobbin thread tension was kept low, at approximately 20 gm.

Figure 20 illustrates both the needle tension effects on the length balance sewing two plies of fabric, as well as the effects of one and three plies on the length ratio.

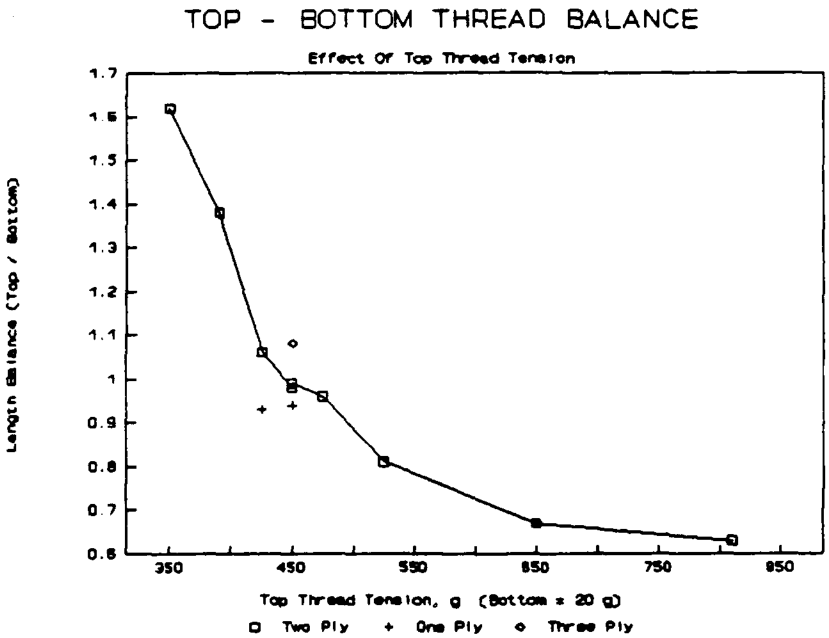

Figure 20 Top Thread Tension Effect on Balance

To further emphasize the ply effects, the needle tension was set at 250 gm and the length balance values were obtained for five samples each of one, two and three plies sewn. The results are given in Fig. 21. This figure, which was taken from work done in a special problems undergraduate project, namely Danna Kelley's project report, illustrates that as the number of fabric plies sewn increases, so does the amount of needle thread consumed in the fabric.

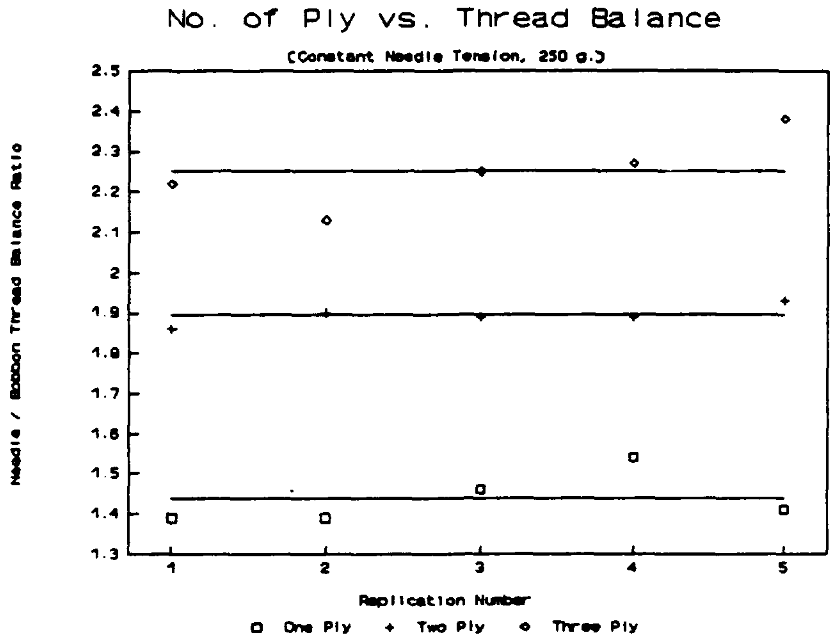

Figure 21. Thread Balance and Number of Fabric Ply

On the basis of the above results, a direct measurement of consumed needle thread, such as could be accomplished by passing the thread over a pulley attached to a low friction encoder, might be the simplest method to differentiate between sewing one or more plies of fabric.

Room temperature and humidity appeared to have a significant effect on the needle tension needed to establish a thread length balance. Danna Kelley reported in her paper that on hot and humid days the thread length balance approached unity close to a needle thread tension of 450 gm, whereas on cool and dry days the corresponding needle tension was as high as 700 gm. Thread finish, the oily or waxy surface lubricant applied by the manufacturer, probably accounts for the humidity sensitivity of thread balance to top thread tension.

These results suggest that further work is needed in this area in order to establish the factors that cause such a significant difference in the findings. Possible causes might be associated with mechanical and frictional properties of the thread used, for example.

2.3.6 Thread Length Consumption Measurement

2.3.6.1 General

A novel experimental method was used to directly measure the time in each machine cycle during which the needle thread is being pulled. The method involved the use of an Eltex piezoelectric transducer. Eltex transducers have been used in the past to monitor yarn breaks in a number of textile manufacturing operations.

2.3.6.2 Results with the Eltex Transducer

Figure 22 shows a superposition of signals obtained with the Eltex transducer while sewing one and two ply of fabric. To obtain this data the transducer was placed between the two tensioning heads located on the front of the Juki sewing machine. The needle thread coming from the first (upper) tensioner was inserted into the "eye" of the transducer and then fed into the lower tensioner so that there were relatively short segments of the needle thread between the transducer and the tensioning heads.

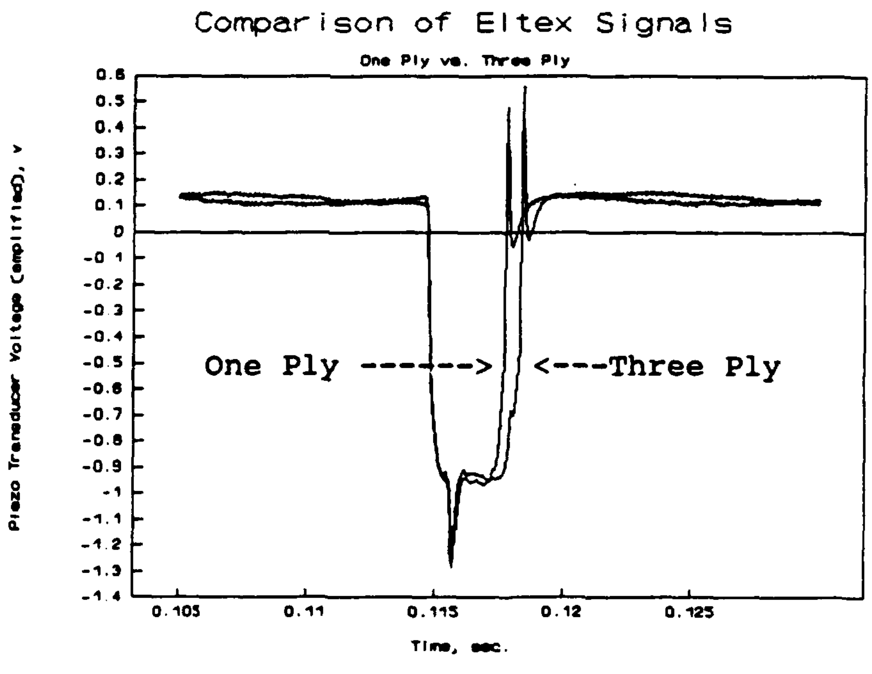

Figure 22 Eltex Data, Three Ply and One Ply Pulses

The electronic signals were captured with the help of Nicolet 310 digital oscilloscope and then processed on our IBM PC XT using DADiSP software. The difference between the dropout signals for one and three ply sewing was found to be about 0.7 msec.

Figure 23 illustrates the difference in duration between the single ply signal and that for an empty bobbin condition. To be able to obtain the latter signal the fabric had to be carefully pushed in the direction of the sewing machine bed in order to allow pulling of the thread through the eye of the needle during sewing. It is evident that this case represents the condition of the least consumption of thread, i.e., the length of thread pulled corresponds to the length of fabric that has traversed under the presser foot.

The above experimental technique will allow a quantitative definition of what it means to have a normal, high or low thread tension both in the needle and bobbin threads. This approach should also be helpful in the detection of sewing defects due to accidental fabric slippage during sewing.

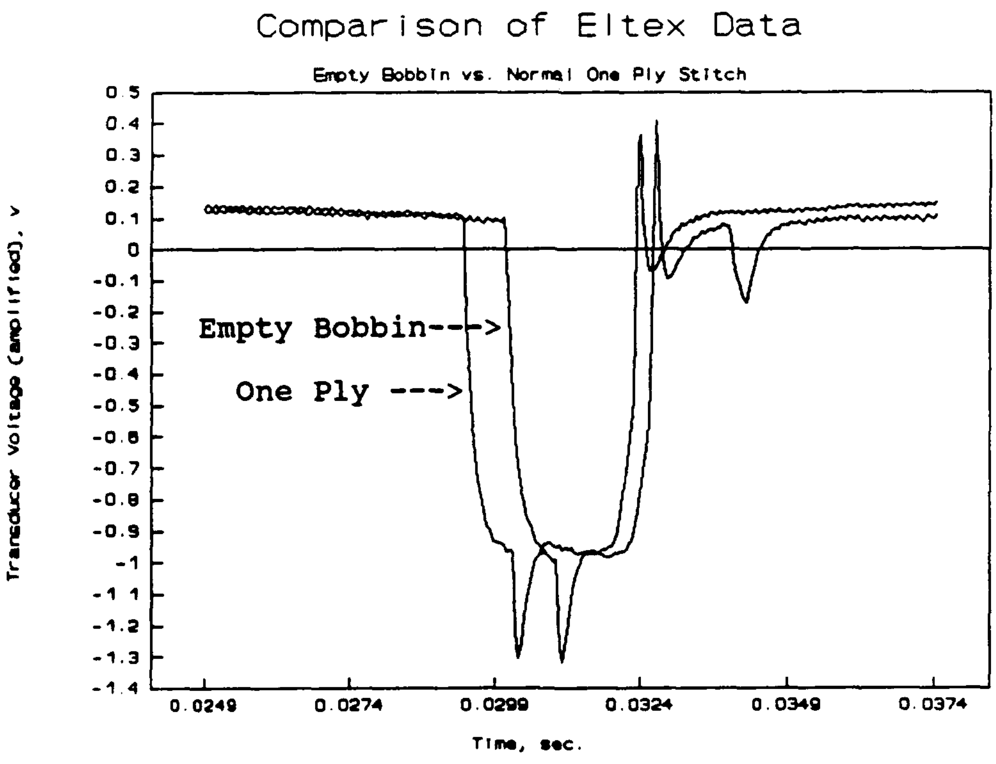

Figure 23 Empty Bobbin vs. Normal One Ply Response

The initial experiments using the Eltex piezoelectric transducer, which are described above, clearly showed that the time during which the needle thread is being drawn by the take-up lever is about one tenth of the machine cycle. Specifically, for a 2100 RPM speed of the sewing machine, one cycle takes about 28.6 ms. While sewing one and three ply of the utility trouser fabric, the corresponding times of thread pull vs. machine cycle were 10.1 % and 12.9 %, respectively.

Therefore, to attain a better understanding of these complex relationships, measurements were made of the relative positions of the needle and the take-up lever. This was accomplished by measuring the position of the needle with reference to the top of the machine bed using a ruler, and the position of the eyelet of the take-up lever using a cathetometer which was located on the floor of the laboratory about four feet away from the sewing machine.

Two measurements were made for each position of the handwheel. The method used for marking the wheel is described below.

A special tape containing 24 white and black regions was attached to the circumference of the handwheel to allow angular positioning of the handwheel from a fixed marker on the body of the sewing machine next to the handwheel. The angular spacing from the edge of one black region to the next amounted to 15 degrees. Data in Fig. 24 was collected in increments representing an angle of rotation of 15 degrees.

The zero(0) on this axis corresponds to the alignment of two timing (red) dots, one on the handwheel and the other on the body of the sewing machine. Another standard position is 30 degrees forward and corresponds to the position of the handwheel (and of the needle) automatically assumed by the sewing machine when stopped. In this case the horizontal alignment is between another pair of timing (white and red) dots.

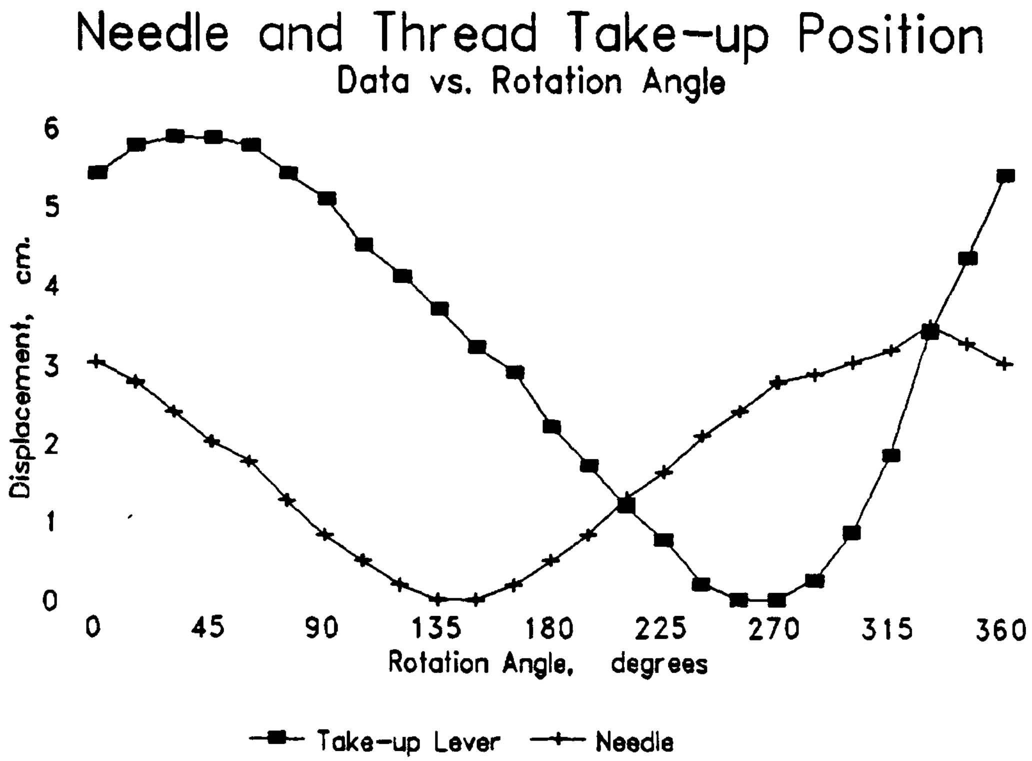

Figure 24 Needle and Thread Take-up Positions During Cycle

The ordinate of Fig.24 represents both the vertical positions of a fixed point on the mount of the needle and the approximate center of the eyelet in the take-up lever referenced to their lowest point of travel. The two curves are appropriately identified in the figure. This representation was intended to compare the relative positions of the needle and the take-up lever for the same angular position of the handwheel.

2.3.7 Top and Bottom Thread Balance

A study was undertaken of uniformity and balance of top thread consumption. The needle thread is referred to as the top thread, and the bobbin thread is the bottom thread. This study was done in support of the previous work with the Eltex sensor which gave a measure of thread consumption on the needle side with each machine

stitch. Variability found in the Eltex data was assessed to be the result of yarn deformation and mass per unit length variation. To further assess this variability, this work was undertaken and is presented in the following.

An experimental procedure was developed wherein a two ply fabric was sewn under conditions of fixed stitch setting and machine speed. The average stitch density was 3.8 stitches per cm. with about 0.4 cm consumption of thread per stitch from each the top and bottom thread sources. Machine speed was mid-range at 3000 RPM.

The primary variable of the study is top thread tension. Advice from several technical staff members of sewing installations led to the conclusion that bobbin tension is held to a minimum subject to the constraint that enough tension be present to assure stability of bobbin thread delivery. A check of bobbins said to be at the correct setting of tension found that the tension was close to 20 g. The value chosen for bobbin tension was that of 20 g, which was checked each day of data collection.

Top thread tensions were varied between having the bobbin thread not pulled into the fabric ply, to having the bobbin thread pulled nearly to the top of the fabric ply. Special attention was paid to having balance of the top and bottom thread loops such that they meet in the middle of the fabric ply.

The data collection procedure was to select successive 10 cm. lengths of fabric and dissect each length for top thread in the first and bottom thread in the second. This was done by cutting each loop in the opposing thread set of stitches so that the thread of concern in that section could be removed intact. The length of thread was measured and is in fact preserved in a research notebook.

Data from the work is seen in two figures following. The variability was sufficient that the day of data collection was an influence on the data. While this is of itself not the reason for variability, temperature and humidity conditions did change remarkably during the period of the test. Fabric and sewing thread finishes are sensitive to conditions at the time of a test. Adding to this density variability of the thread and fabric accounts for variability in the results. Figure 25., following, is of data collected.

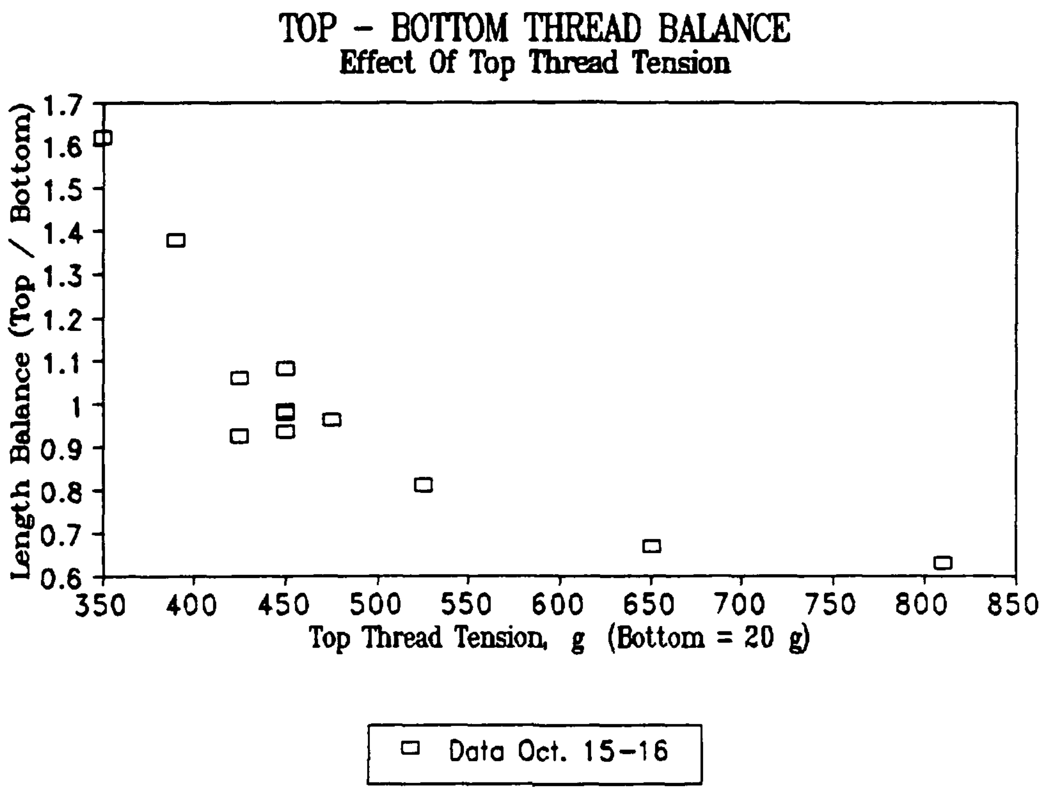

Figure 25 Data Collected -Top / Bottom Thread Balance

There appears to be some relation of the ratio of top and bottom thread lengths and top thread tension in Figure 25. The curve has an appearance similar to an exponential decay function, which could be related to the exponential tension ratio function used to describe friction in wrapping or over curved surfaces.

In the vicinity of 450 g, the fabric appears to be in balance with a ratio of top to bottom thread length approaching 1.0. The replications that day gave rise to some confidence in machine settings. This balance, it is now found, is disturbed by changing environmental conditions. Very cool, dry outside air and a failed environmental control system led to very dry conditions in the lab.

Evidently, this markedly affected the sewing process. Figure 26 below is of data taken during the time of these uncontrolled conditions. It shows more variability and less of a trend for top thread position to follow top thread tension.

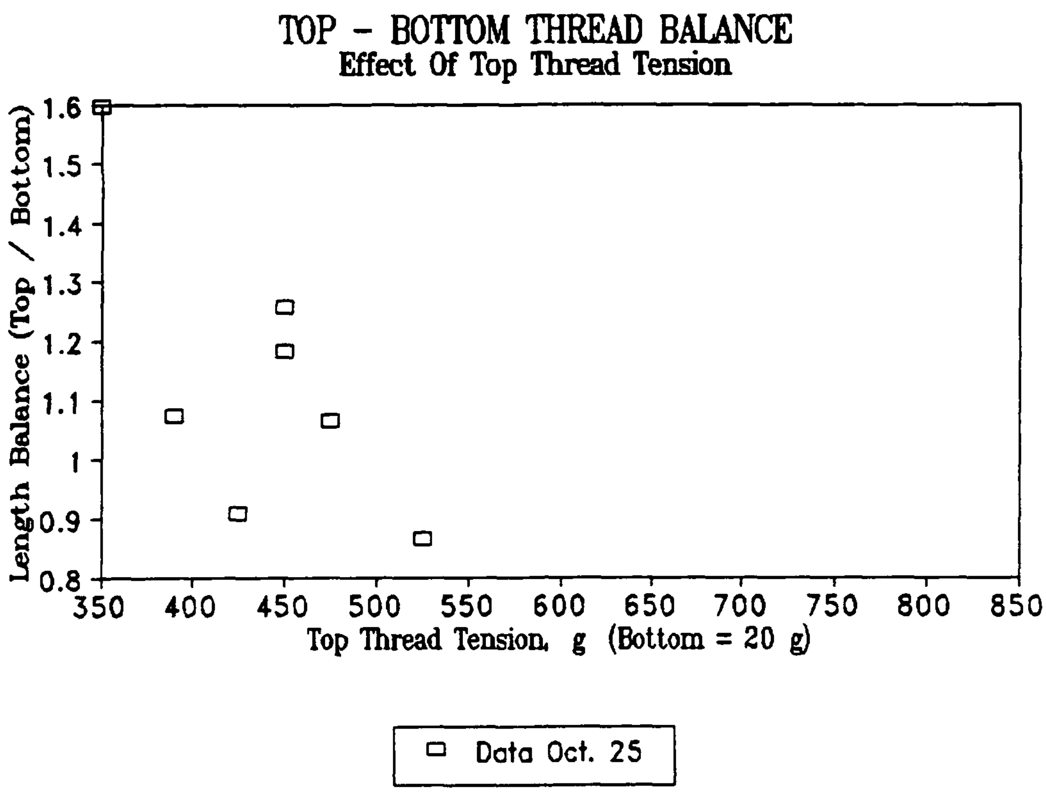

Figure 26 Data Collected with Reduced Environmental Control

Here the tension range of 425 g to 450 g gives almost 30% change in the thread balance. Friction and fabric/yarn variability are having a serious affect on sewing. One conclusion of the look at thread balance is to conclude that uniformity, including that of the environment, has considerable effect on sewing.

Because of this variability due to sewing room conditions, a third set of fabrics were sewn with varying top thread tension. Incidentally, top and bottom threads were removed from one hundred stitch seam lengths in these tests to get a reasonably accurate measure of top and bottom stitch lengths.

Note that conditions other than sewing room environmental conditions are the same in the figures 25. and 26 above, and figure 27 following.

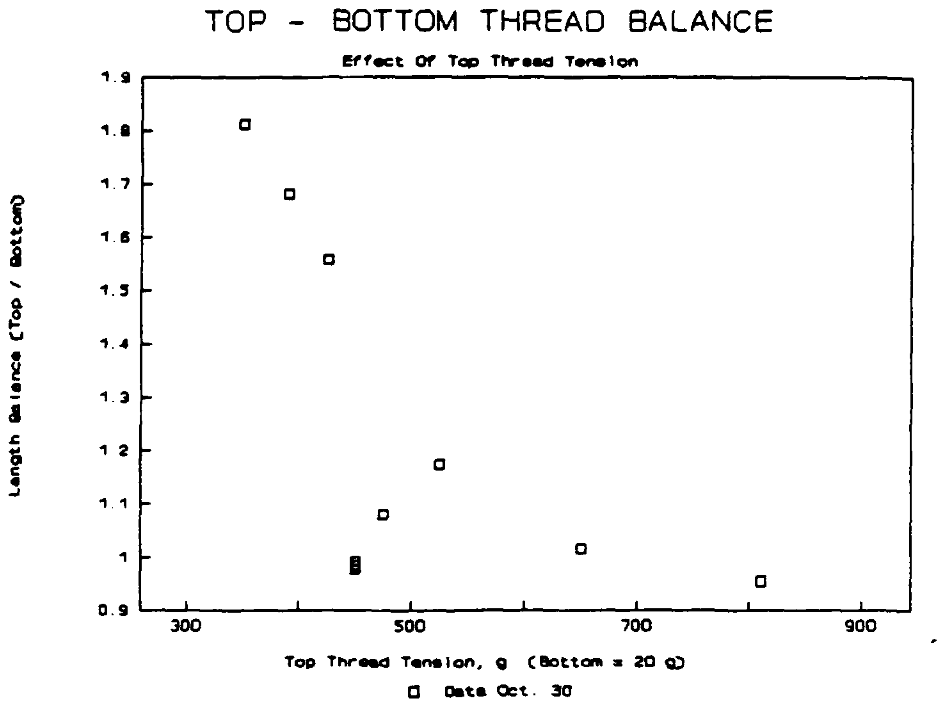

Figure 27. Thread Balance in a Lockstitch Seam

On this date, balance, which is the ratio of needle to bobbin thread consumption of 1.0, occurs at about 700 grams thread tension. Later work with sewing plants and maintenance personnel pointed to a standard value of 200 grams for the needle (or top) thread tension. At that tension level, more than twice as much top thread is consumed, compared with bobbin thread consumption. Clearly, the balance point is not at the center of the ply being sewn, but rather two thirds of the distance from top to bottom, close to the bottom side.

To operate at excess tension in order to form a more "perfect" lockstitch creates the potential for thread breaks. The sewing thread has thick and thin places to some degree in any circumstance. Work by another student found the stress-strain relation for the sewing thread. This is shown in figure 28. following.

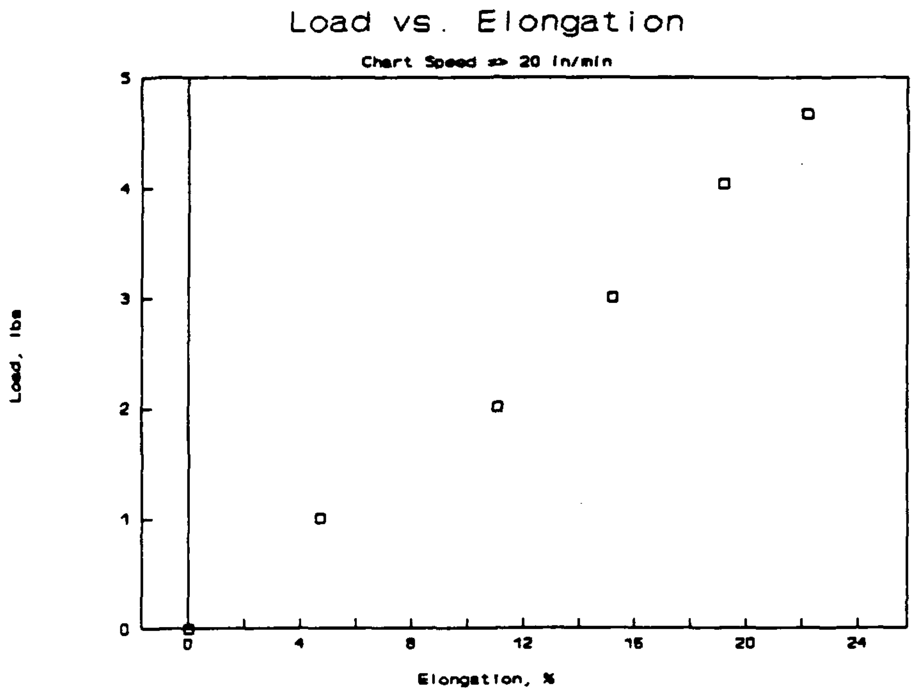

Figure 28. Sewing Thread Strength v. Elongation

This figure shows that achieving balance may take about 50% of the total yarn strength. Preloading the yarn to this extent is of itself reasonably safe, but when sewing loads during fabric penetration and loop formation are considered, this increases the chance for thread breaks significantly. The value recommended for top thread tension, again, is about 200g.

The take-up consumption is affected by thread tension and number of plies, notably whether or not the same length of thread is consumed at each stitch, and by the stitches per inch. Therefore, a consumption variation can result from one or more basic sewing defects. Thread consumption in sewing has the chance of being detected by the Eltex piezoelectric sensor, and because it has been used successfully in other textile applications, the device is seen as a reliable, acceptable tool for apparel application. A thread or yarn thin place can undergo excessive elongation after the consumption sensor, which causes a false reading of a short stitch. This is not a sewing defect, but rather a thread defect. Similarly, changes in yarn finish with humidity and temperature were seen in figures just above to cause changes in thread balance for fixed

tension settings. This too is a thread problem of another type.

Variability at each needle penetration of the fabric affects how easily or simply a circuit can be designed to do a measurement. One study showed that some measurement techniques cannot find a single stitch fault. Fortunately, single stitch faults are not consequential to many seams in apparel manufacturing. For example, seam "blow out" in washing of Navy utility trousers at the felled seam occurs only when ten or so stitches are misformed. This fault is detectable overall. Whereas the first misformed stitch produces a signal which falls at the extreme of an allowable error zone, ten such stitches produce an average which falls over a warning limit.

2.3.8 Acoustic Measurements of Needle Wear

A series of experimental runs were made by Bernard Gunn, a M.S. level graduate student working with Dr. Sikorski, to check if there are significant differences between the acoustic spectra for different conditions of wear of sewing needles. The assumption was that should there be a measurable difference in the acoustic energy generated during sewing between a fresh and a worn sewing needle, it should be possible to devise automatic means to alert the machine operator as to when a worn needle should be replaced.

The experiments were conducted by placing a small piezoelectric transducer on the body of the sewing machine in the vicinity of the needle shaft and away from the throat plate. This prevented possible interference of the transducer with the sewing process. The amplifier gain was set a 52dB to bring the electrical signal into the workable range of the Nicolet 310 digital oscilloscope.

The experimental procedure was as follows. The acoustic spectral signatures were obtained for two needles, one brand new with a sharp tip and the other with a mechanically abraded tip to a radius about five times greater than the new needle. Four traces for each needle were then analyzed with the help of DADiSP software. The frequency range analyzed was 0-25 kHz. After obtaining four FFT spectra, an average spectrum for each needle was generated and the results compared. Areas under the average spectra were used to compare the two needle conditions. The variability of areas from trace to trace for each needle was also evaluated in addition to obtaining the areas for each average spectrum. The results obtained were an average and range for each:

Area(sharp needle)=(329.9 $\pm$ 32.5) Volt x Hertz and

Area(worn needle)=(422.6 $\pm$ 140.2) Volt x Hertz.

These results show that the acoustic energy generated by the blunted needle was about 28% greater than for the new, sharp needle. The variability of areas from experiment to experiment was about 33% for the blunted needle compared to about 10% for the new needle. The

above results were obtained for a fixed sewing speed of 2100 RPM.

The results reported above suggest the feasibility of developing a needle wear detector. An RMS voltage signal generated by the transducer during a short run of sewing at a constant RPM could be compared with the previously recorded value for a new needle. In this way the operator could be alerted when the needle reaches a predetermined amount of wear.

Further research done under a no cost extension to the project allowed for completion and reporting on student special projects and this graduate thesis. Needles blunted intentionally, and used needles from industrial sources were used to collect information on their spectra versus degree of wear as determined by measuring the radius of curvature of the needle tip under a scanning electron microscope. The factory at DPSC was quite helpful in producing needles with wear of four, eight and twelve hours. Results of measurement of tip curvature is given in Figure 29. following.

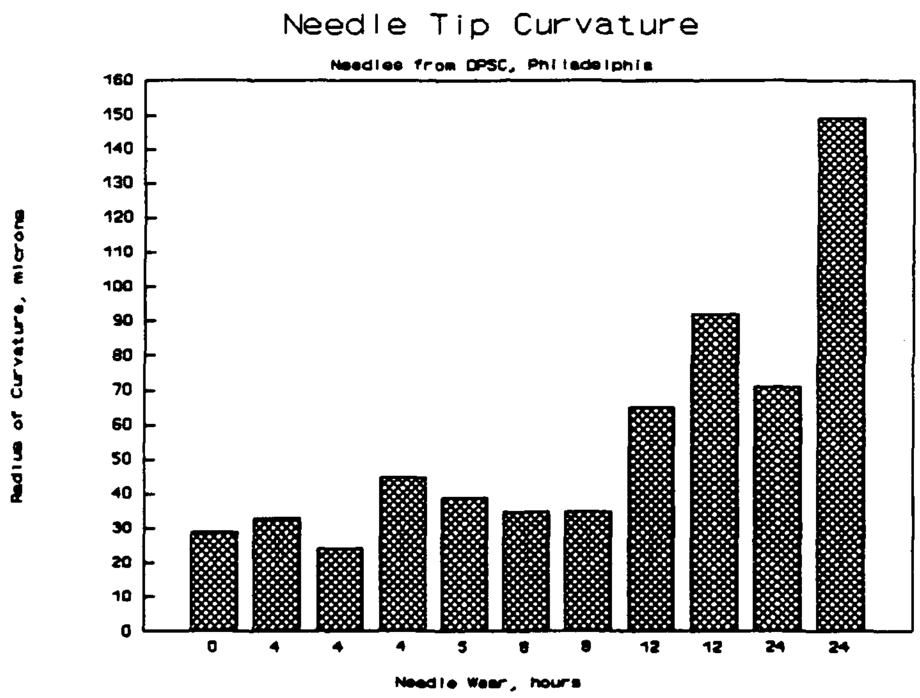

Figure 29. Tip Curvature, DPSC Samples

The needles from DPSC allowed data to be collected via acoustic energy analysis that showed a clear relation of energy to wear in one passband. A bandpass filter centered at 10500 Hz, Q of about 100, would see 0.5v output for a new needle, 0.7v after four hours and

0.9v after eight hours of use, based upon the transducer and amplifier used in the student's tests. The relation was almost linear. Most sewing operations change the needle every eight hours, or about one million cycles of the needle.

Needles are surface hardened to withstand the abrasion of sewing. The observation of needle tips under a scanning electron microscope showed that about 25% of all needles sent to us from industry were found to have broken tips. The needles were specified as simply having been taken out of service without regard for reason. The tip breaks had the characteristic surface of brittle fracture in metal. This suggests that these breaks were caused by striking something solid. This may be fasteners on the apparel or parts of the sewing machine that are out of alignment or misadjusted. Assistance to Mr. Gunn's thesis were given by Tom Hammonds and Abubakar Bah.

Additional information is presently available on the acoustic measurements of needle wear. The comparison of acoustic energy generated by the blunted needles as compared with the new, sharp needle indicates a 28.4% increase for the less blunted needle and 38.1% for the more blunted one.

The FFT spectra for the three needles are shown in figure 30.

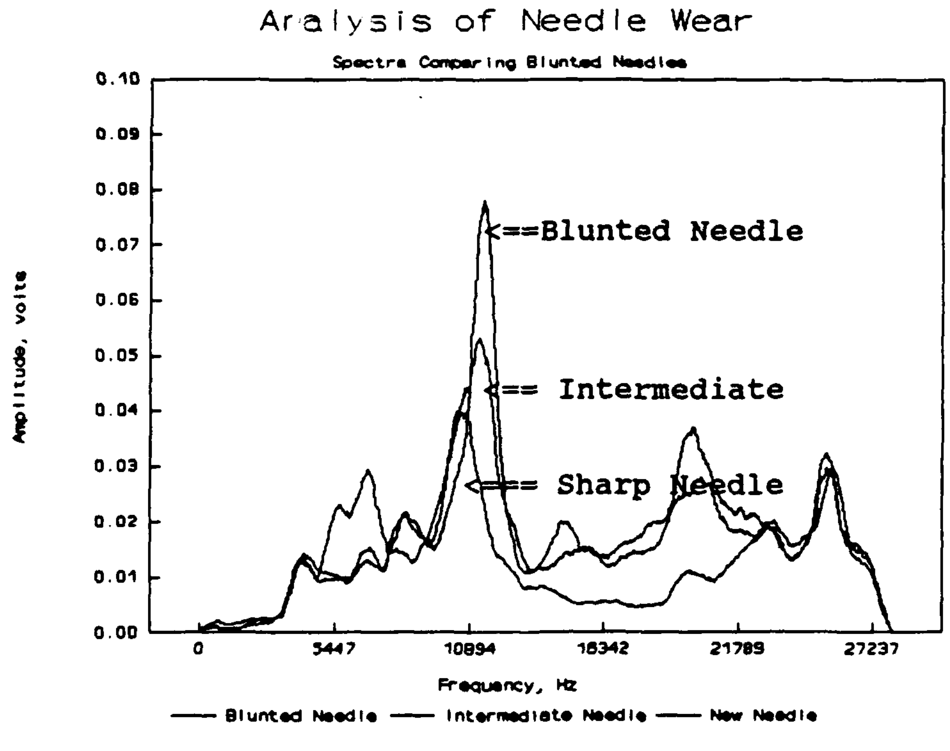

Figure 30. Needle Wear Comparison

The 4-7 kHz frequency window does not allow the differentiation between the two blunted needles. However, two other frequency bands, one around 10 kHz and the other centered around 20 kHz do. Narrow frequency band filters around the latter two center frequencies could be used for the evaluation of the degree of wear of such needles.

Eight "worn", or rejected Schmetz needles were obtained through the courtesy of the Tennessee Apparel Corporation. These needles were used in high speed (5000 RPM) Duerkopf 211 sewing machines for sewing GORTEX fabrics. Microscopy showed that these needles have blunted tips, and others of different design show mechanical damage in the vicinity of the needle's eye. Another rejected needle was obtained through the courtesy of the Southern Tech Apparel Research Center, a 134 CL SUK Schmetz medium ball sewing needle which was used for sewing pockets in utility denim trousers on an Adler 804 sewing machine. A visual comparison of this and a new needle indicated a minor roughening of the tip of the used needle and a very severe wear of the sides of the needle on both sides of the needle eye, causing thread breaks.

A student, Arlene Stark, continued work on measuring the acoustic spectra of the sewing machine in conditions of thread versus no thread in normal two ply seaming. Her research added 3000 RPM data to that which was found earlier. The following came from this work.

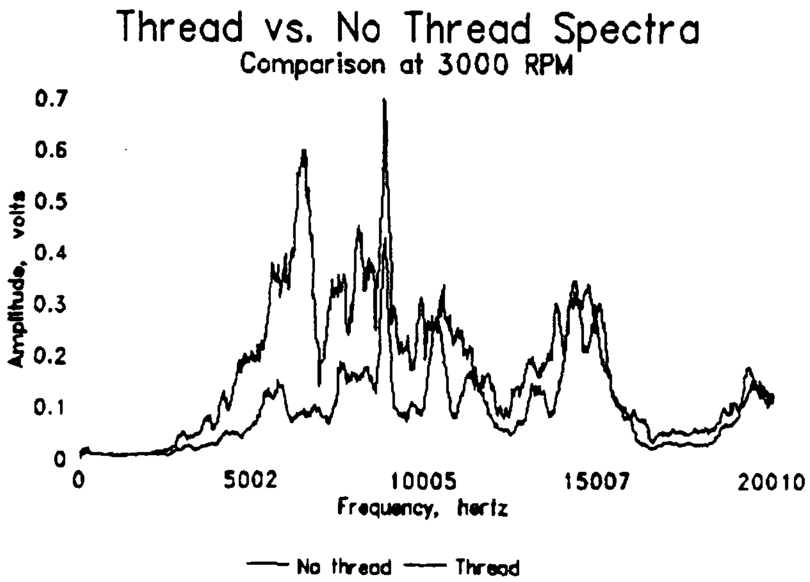

Figure 31. Thread v. No Thread (Normal RPM)

Figure 31 illustrates again that a frequency band can be found where thread break can be identified. Efforts to determine whether integration of the area under the curve is sufficient had difficulty at low frequency. This concept was to have an all purpose, all frequency thread break detector. For reasonable sewing speeds, it is possible to use an op amp integrator, but research indicated that the broad approach would not be adequate at all speeds. Most industrial sewing is done at fixed speed. Furthermore, the new sewing machine drives achieve operating speed in about ten stitch cycles. The result is that fixed band detection should be reliable.

Research into fiber optic detection of top thread as it passes over the bobbin case led to the determination that this method is feasible as well. The findings included that straight fiber optics were insufficient to both detect a missing top thread and provide sufficient clearance for bobbin changing. When an integral lens is included with the fiber optics, reliable thread detection was achieved with an optimum placement from the bobbin case of 2.5" separation. This allows adequate clearance.

3.0 Plans for the Implementation Phase: Industrial Application

Designs for the low-cost circuits to implement fault detection are to be generated and built in prototype form. In-plant testing of the prototypes will be conducted at least two facilities, but more likely three facilities. Levi Strauss through their Technical Center in Richardson, TX, Tennessee Apparel and the Factory at DPSC in Philadelphia are strong candidates for the on site tests. Also, the Johnson & Johnson sewing plant in El Paso, TX has offered its facilities for this prototype development effort. Levis will coordinate design efforts for their application at Richardson, then permit tests in the regional plant most suited to the particular application. Similarly, technical or maintenance personnel at Tennessee Apparel and at the DPSC Factory will be consulted during prototype development. The key element is rapid feedback from the plants, allowing time for redesign and refinement in the design process. The final report for the Implementation Phase is to be written such that independent firms or individuals may duplicate what was done in this project.